ROUX

Date: August 17, 2018

To: Mike Cirian, USEPA

From: Laura Jensen, Roux

CC: John Stroiazzo, Glencore
          Steve Wright, CFAC
          Dick Sloan, MDEQ
          Andrew Baris, Roux
          Michael Ritorto, Roux
          Gary Long, EHS Support, LLC

Subject: **Technical Memorandum: Proposed Wildlife Exposure Modeling Approach to
          Support the Baseline Ecological Risk Assessment at the Columbia Falls
          Superfund Site
          Former Columbia Falls Aluminum Company Aluminum Reduction Facility
          Columbia Falls, Montana**

On behalf of Columbia Falls Aluminum Company, LLC (CFAC), Roux Environmental Engineering and Geology, D.P.C. (Roux) and EHS Support, LLC prepared the attached Technical Memorandum for Proposed Wildlife Exposure Modeling Approach to Support the Baseline Ecological Risk Assessment (BERA) for the CFAC Superfund Site in Columbia Falls, Montana. This memorandum has been prepared as part of the ongoing Remedial Investigation/Feasibility Study (RI/FS) being conducted pursuant to the Administrative Settlement Agreement and Order on Consent (AOC) dated November 30, 2015 between CFAC and the United States Environmental Protection Agency (USEPA) (CERCLA Docket No. 08-2016-0002).

Should there be any questions or comments on this submission, please do not hesitate to contact me at (631) 230-2300.

Sincerely,

Laura Jensen

Laura Jensen, P.G. (NY)
Project Hydrogeologist

MEMO

To: Andrew Baris, Roux

From: Gary Long

CC: Michael Ritorto, Roux
Laura Jensen, Roux
Tom Biksey, EHS Support

Date: August 17, 2018

Re: *Technical Memorandum: Proposed Wildlife Exposure Modeling Approach to Support the Baseline Ecological Risk Assessment at the Columbia Falls Superfund Site*
Former Columbia Falls Aluminum Company Aluminum Reduction Facility
Columbia Falls, Montana

Introduction

This technical memorandum describes the approach for estimating dietary exposure to terrestrial and semi-aquatic wildlife in the Baseline Ecological Risk Assessment (BERA) for the Columbia Falls Aluminum Company (CFAC) Superfund Site in Columbia Falls, Montana. The technical memorandum was prepared as an interim deliverable to supplement the general risk assessment framework provided in the *Baseline Ecological Risk Assessment Work Plan* (BERA WP) submitted to the United States Environmental Protection Agency (USEPA) and Montana Department of Environmental Quality (MDEQ) in November 2017 and revised in May 2018 (EHS Support, 2018).

The technical memorandum presents the modeling approach, preliminary exposure parameters, bioaccumulation relationships, and toxicity reference values (TRVs) that are proposed to evaluate dietary pathways to terrestrial and semi-aquatic wildlife receptors that may be exposed to bioaccumulative constituents of potential ecological concern (COPECs) at the Site. Bioaccumulation relationships and TRVs are proposed for potentially bioaccumulative COPECs identified in the *Screening Level Ecological Risk Assessment* (SLERA) conducted based on Phase I Site Characterization data (Roux Associates, 2017). Further identification of potentially bioaccumulative COPECs will be conducted based on a re-screening of the Phase I Site Characterization data with additional data being collected in accordance with the Phase II Site Characterization Sampling and Analysis Plan (Roux Associates, 2018). In addition, further evaluation of the appropriateness of exposure assumptions and model parameters presented in this technical memorandum may be warranted in the BERA to reduce uncertainty in dietary exposure estimates used to characterize risk to wildlife through dietary pathways. The BERA Report will include an appendix that provides documentation and justification for the exposure parameters and model assumptions used in dietary exposure models for the Site.

The following sections describe the identification of preliminary bioaccumulative COPECs to evaluate via dietary exposure pathways, the dietary exposure modeling approach and parameters, and the preliminary selection of wildlife TRVs.

Identification of Bioaccumulative COPECs

COPECs identified in the SLERA and BERA WP based on the preliminary analysis of Phase I Site Characterization data (Roux Associates, 2017) were evaluated to identify potentially bioaccumulative constituents for dietary exposure modeling in the BERA. COPECs were conservatively identified in the SLERA based on comparisons of maximum concentrations in the Phase I Site Characterization datasets to minimum ecological screening values (ESVs). In addition, the BERA WP identified additional COPECs based on detected constituents lacking ESVs. COPECs with the potential to bioaccumulate were identified for dietary exposure modeling in the BERA based on satisfaction of one or more of the following criteria:

1. Constituents identified as Persistent, Bioaccumulative, and Toxic Constituents as part of the USEPA Toxics Release Inventory (TRI) Program
2. Constituents identified as important bioaccumulative constituents in USEPA (2000)
3. Organic constituents with a log octanol-water partitioning coefficient (log K_{ow}) greater than 3.5 based on USEPA (2000)
4. Constituents with USEPA Ecological Soil Screening Levels (Eco-SSLs) derived for birds or mammals (USEPA, 2005a).

Table 1 presents a preliminary list of COPECs that will be included in dietary exposure modeling in the BERA based on the above criteria. The preliminary list of bioaccumulative COPECs presented in Table 1 will be re-evaluated based on the combined results of the Phase I and Phase II Site Characterization sampling. As indicated in the BERA WP, relevant exposure data from the Phase I and Phase II Site Characterization datasets will be re-screened to identify COPECs based on conservative comparisons of maximum concentrations to minimum ESVs. COPECs identified in the re-screening of the combined Phase I and Phase II datasets that have the potential to bioaccumulate based on one or more of the above criteria will be included in the dietary dose modeling presented in the BERA. Dietary exposure to these potentially bioaccumulative COPECs will be evaluated in a manner consistent with the approach described in this technical memorandum.

Dietary Exposure Modeling

The evaluation of potential exposure via direct and incidental ingestion pathways will be conducted based on a tiered approach in accordance with the USEPA guidance for conducting probabilistic ecological risk assessment (USEPA, 2001). The tiered approach will include the following ingestion models to quantitatively assess potential risks to representative wildlife receptors:

- Deterministic exposure modeling: Based on conventional single point estimates of exposure point concentrations (EPCs) and typical exposure parameters. Deterministic exposure models will be developed based using a tiered approach that incorporates preliminary and refined exposure estimates:
    - Preliminary exposure estimates: Screening-level exposure assumptions based on maximum EPCs and conservative exposure assumptions.

- - Refined exposure estimates: Refined exposure estimates using EPCs based on conservative estimates of the mean concentrations at the site, assuming random foraging throughout each exposure area and more realistic exposure assumptions.

    Further discussion of the assumptions supporting the preliminary and refined exposure estimates are provided in relevant sections within this technical memorandum.
- Probabilistic exposure modeling: If estimated doses based on refined deterministic modeling exceed doses associated with lowest-observed-adverse-effect levels (LOAELs), probabilistic models may be developed to estimate exposure based on the distributions of EPCs and exposure parameters to account for variability and/or uncertainty in model parameters.

The following sections describe the basic model structure, receptor-specific exposure factors, exposure variables, bioaccumulation relationships, and area use factors that will be used for dietary exposure modeling in the BERA.

Model Structure

The underlying algorithm of the dietary exposure model is the same for deterministic and probabilistic approaches. However, deterministic estimates use single, discrete values for model parameters (i.e., representative of a typical or a worst case), whereas probabilistic estimates use a distribution of values for model parameters to account for the inherent variability and/or uncertainty in the estimation of those parameters. Procedures for calculating probabilistic exposure estimates are consistent with USEPA (2001) guidance on probabilistic ecological risk assessments and USEPA (1997) guidance on Monte Carlo analyses. The following sections describe the model structure and the general procedures for deterministic and probabilistic modeling.

Deterministic Modeling Procedures

Deterministic exposure estimates will be based on comparisons of receptor-specific estimated daily doses (EDDs) calculated from simple dose rate models to TRVs. Dietary exposure estimates consider receptor-specific exposure factors, including typical dietary composition, and exposure variables that represent site-specific measurements of COPEC concentrations in exposure media. The general form of the dose rate model used to calculate EDDs is:

$$EDD = \frac{1}{BW}\sum_{i=1}^{N}\left(FIR_{dw} \times \sum_{j=1}^{M}\left(f_j \times C_j\right) + SIR_{dw} \times C_{sub} + WIR \times C_{sw}\right)_i \times AUF_i \qquad (1)$$

where:
N = Number of exposure areas within the typical receptor home range
M = Receptor-specific dietary items
BW = Receptor-specific body weight (kg)
FIR_{dw} = Receptor-specific daily food ingestion rate (kg/day, dry weight)
f_j = Proportion of dietary item j to total dietary composition
C_j = COPEC concentration in dietary item j (mg/kg tissue dry weight)
SIR_{dw} = Receptor-specific incidental substrate ingestion rate (kg/day, dry weight)
C_{sub} = COPEC concentration in substrate (mg COPEC/kg substrate, dry weight)
WIR = Receptor-specific daily drinking-water ingestion rate (Liters (L)/day)
C_{sw} = COPEC concentration in unfiltered surface water (mg COPEC/L)

AUF_i = Area use factor for a given exposure area and receptor

For receptors with foraging ranges that are smaller than a given exposure area, the EDD will be calculated based on EPCs derived from data collected within that exposure area. If the foraging range of a receptor is greater than an exposure area, the EDD will be calculated as the sum of area use factor (AUF)-weighted doses obtained from the exposure areas within the typical home range of the receptor. Further explanation regarding the calculation of AUFs is presented in the *Area Use Factors* section of this technical memorandum.

As stated in the BERA WP, dietary exposure to small home range receptors will also be evaluated based on point-by-point comparisons of measured COPEC concentrations in biologically relevant sampling intervals to estimated soil or sediment benchmark concentrations that are back-calculated from TRVs. Consistent with the approach used to calculate USEPA Eco-SSL values (USEPA, 2005a), the general exposure model presented in Equation 1 will be used to back-calculate soil or sediment benchmarks for each representative small home range receptor by setting the EDD equivalent to the TRV and solving for the C_{sub} value.

A modified version of the dietary exposure model presented in Equation 1 will be used to evaluate the potential additive exposure to dioxin/furan compounds in surface soil sampled within the Main Plant Area and adjacent areas. Additive exposure to dioxin/furan compounds will be evaluated using the toxicity equivalence methodology consistent with USEPA (2008a). The modified dietary exposure model will calculate an EDD for the 17 individual dioxin/furan compounds in each sample based on the general model presented above. The EDD for each compound will be multiplied by the compound-specific toxicity equivalence factor (TEF) for birds or mammals relative to the toxicity of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) to estimate the toxicity equivalence concentration (TEC) for each compound (Van den Berg et al., 2006; Van den Berg et al., 1998; USEPA, 2008a). TECs of the 17 dioxin/furan compounds will be summed to calculate an overall TEC:

$$TEC = \sum_{n=1}^{k} EDD_n \times TEF_n \qquad (2)$$

where:
TEC = Toxicity equivalence concentration
EDD_n = Estimated daily dose calculated for dioxin-like chemical n
TEF_n = Toxicity equivalence factor for dioxin-like chemical n
k = Number of toxic dioxin-like chemicals in the mixture

The TEC will be evaluated relative to dietary TRVs for 2,3,7,8-TCDD derived for birds and mammals.

Probabilistic Modeling Procedures

Procedures for calculating probabilistic exposure estimates will be consistent with USEPA (2001) guidance on probabilistic ecological risk assessments and USEPA (1997) guidance on Monte Carlo analyses. As warranted based on the outcome of deterministic exposure estimates, Monte Carlo simulations may be conducted using the statistical computing and graphics language R (R Core Team, 2013) to estimate the EDD and the average estimated daily dose (AEDD) distributions for each receptor based on the following procedures.

To estimate the EDD distribution for a receptor:
1. R will be used to randomly select a body weight (BW) from its literature-derived distribution and to calculate the corresponding food ingestion rate (dry weight) (FIR_{dw}), incidental substrate ingestion rate (dry weight) (SIR_{dw}), and drinking water ingestion rate (WIR).
2. f_i will be selected based on dietary composition.
3. C_i and C_{sub} will be randomly selected from their corresponding distributions from site-specific concentrations measured during the Phase I and Phase II Site Characterization sampling.
4. EDD will be calculated using Equation (1) above.
5. Steps #1 to #4 will be repeated a pre-set number of times to estimate the EDD distribution; the number of iterations will be pre-set at 10,000 based on convergence criteria provide in Sample et al. (1996a).

To estimate the average estimated daily dose (AEDD) distribution for a receptor:
1. The Bootstrapping Method will be used to randomly select N number of EDD from the EDD distribution above, where N = Number of days/year the receptor is exposed within site exposure areas.
2. AEDD, defined as the arithmetic mean of the selected EDDs, will be calculated.
3. Steps #1 and #2 will be repeated a pre-set number of times to estimate the AEDD distribution; the number of iterations will be pre-set at 10,000 based on convergence criteria provide in Sample et al. (1996a).

The following section presents the basis for selecting receptors of concern and model parameters used in deterministic and probabilistic dietary exposure modeling.

Receptors of Concern

Ecological exposure areas identified in the BERA WP may support multiple terrestrial and semi-aquatic wildlife receptors of concern (EHS Support, 2018). As indicated in the BERA WP, exposure to avian and mammalian wildlife receptors will be evaluated based on dietary exposure pathways using the approach presented in this technical memorandum. Exposure to other ecological receptors of concern, including fish, reptiles, and amphibians, will be evaluated based on direct contact exposure pathways in the BERA (EHS Support, 2018).

Several surrogate species were identified in the BERA WP as representative species to evaluate exposure to mammalian and avian receptors based on feeding guild using dietary exposure models. Representative terrestrial species for each receptor group based on feeding guild include:

Receptor Group	Scientific Name	Common Name
Mammalian Fauna		
Herbivorous mammal	*Microtus pennsylvanicus*	Meadow Vole
Insectivorous mammal	*Blarina brevicauda*	Northern Short-tailed Shrew
Carnivorous mammal	*Mustela frenata*	Long-tailed Weasel
Avian Fauna		
Herbivorous bird	*Zenaida macroura*	Mourning Dove
Invertivorous bird	*Scolopax minor*	Woodcock
Carnivorous bird	*Buteo jamaicensis*	Red-tailed Hawk

Representative semi-aquatic species for each receptor group based on feeding guild include:

Receptor Group	Scientific Name	Common Name
Mammalian Fauna		
Piscivorous mammal	*Mustela vison*	Mink
Avian Fauna		
Invertivorous bird	*Cinclus mexicanus*	American Dipper
Piscivorous bird	*Megaceryle alcyon*	Belted Kingfisher

In addition to the mammalian and avian receptors representing feeding guilds expected to be present at the site, potential dietary exposure to four federally threatened (or proposed threatened) species identified by the United States Fish and Wildlife Service Information for Planning and Consultation[1] (USFWS IPaC) will also be evaluated (EHS Support, 2018):

Scientific Name	Common Name	Status	Potential Exposure Area – General Habitat
Mammals			
Lynx canadensis	Canada Lynx	Threatened	Terrestrial – Boreal spruce-fir forest habitat
Ursus arctos horribilis	Grizzly Bear	Threatened	Terrestrial – Relatively undisturbed mountainous habitat
Gulo gulo luscus	North American Wolverine	Proposed Threatened	Terrestrial – High elevation habitat near the tree-line
Birds			
Coccyzus americanus	Yellow-billed Cuckoo	Threatened	Terrestrial – Dense, cottonwood-dominated forests canopies

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[1] Accessed at: https://ecos.fws.gov/ipac

The following sections present receptor-specific exposure factors selected to estimate dietary doses to wildlife receptors of concern.

Receptor-Specific Exposure Factors

Receptor-specific exposure factors were identified to estimate exposure and area use for identified wildlife receptors of concern evaluated in dietary exposure models. Receptor-specific exposure factors used in the dietary exposure models include:

- BW
- FIR_{dw}
- SIR_{dw}
- WIR
- Dietary composition, proportion of dietary item j to total diet (f_j)
- AUF

Receptor-specific exposure parameters will be derived from general literature sources and compilations of exposure factors developed to support dietary exposure modeling (e.g., USEPA, 1993; USEPA, 2007a; USCHPPM, 2004; Sample and Suter, 1994).

Deterministic exposure modeling uses exposure factors that are representative of typical or average (e.g., mean parameter) exposure conditions. Probabilistic exposure modeling evaluates a range of potential exposure factors to capture the individual- and population-level variation in exposure factors that are likely to occur within exposure areas. A summary of exposure factors that will be used in the deterministic exposure model is presented in **Table 2**. The approach for selecting exposure factors for dietary exposure models is summarized below.

Body Weight

In deterministic exposure models, representative body weights will be estimated as arithmetic mean values of adult body weights reported in the literature or midpoints of the range of body weights when arithmetic mean values are not available (**Table 2**). When body weights are available for both sexes, the more conservative (lower) estimate of the average body weight will be selected. Minimum body weights were identified from the available literature as conservative body weight estimates for special status species, including Canada lynx, grizzly bear, and North American wolverine (**Table 2**).

For probabilistic exposure estimates, distributions of potential body weights of adult receptors will be estimated using R based on available arithmetic mean (μ) and standard deviation (σ) of body weights reported in the literature for the selected receptors (**Table 2**). Normal distributions of potential body weights will be assumed for each receptor. Estimated distributions of potential body weights will be truncated to the range of body weights reported in the literature to avoid unrealistic estimates of receptor body weight (i.e., the distribution of potential body weights will not include values that are greater than or less than the range of body weights reported in the literature).

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Food Ingestion Rate

Food ingestion rates FIR_{dw} will be estimated based on receptor-specific BW values using appropriate empirical allometric (scaling) relationships developed by Nagy (2001). Nagy (2001) derived allometric relationships for various avian and mammalian feeding groups based on taxon, habitat, and diet. For each wildlife receptor, the most appropriate allometric equation from Nagy (2001) will be used to estimate dry weight food ingestion FIR_{dw} as a function of BW (**Table 2**):

$$FIR_{dw} = a \times BW^b \qquad (3)$$

where:
FIR_{dw} = Dry weight food ingestion rate (kg dry weight/day)
BW = Receptor-specific body weight (kg)
a and b = Parameters whose values are specific to an allometric equation (see **Table 2**)

In deterministic exposure models, the receptor-specific FIR_{dw} estimated from the appropriate allometric relationship will be used based on average body weight in the point estimate calculation of the EDD. For probabilistic exposure models, distributions of FIR_{dw} will be developed based on allometric relationships using randomly selected body weights from the body weight distribution described in the preceding section. The randomly selected body weights will be used to estimate corresponding FIR_{dw} values using the appropriate form of Equation 3 for the receptor of concern. The resulting distribution of FIR_{dw} will be representative of the range of feeding rates that may be observed within a given receptor population as a function of the potential range of body weights of individuals within the population.

Potential distributions of FIR_{dw} values will not be developed directly from literature-reported values for the following reasons:
- Literature-derived FIRs (primarily mean values) are insufficient to generate robust distributions.
- It is inappropriate to evaluate FIR_{dw} independent of BW; if BW and FIR_{dw} are independent in a probabilistic simulation, a receptor at the lower end of the BW distribution may be unrealistically paired with a FIR_{dw} value at the higher end of the FIR_{dw} distribution.

Incidental Substrate Ingestion Rate

Exposure models account for the dietary intake of soil or sediment (substrate) that may be ingested incidentally because of the feeding behavior of select receptors or indirectly through the ingestion of prey. Incidental substrate ingestion rates (SIR_{dw}) will be estimated based on the average incidental substrate ingestion as a percentage of dry food intake based on FIR_{dw} values derived by Nagy (2001) using the approach described in the preceding section. SIR_{dw} will be expressed as a proportion of the dry food ingestion rate, as follows:

$$SIR = FIR_{dw} \times \left(\frac{Ps}{100}\right) \qquad (4)$$

where:
SIR_{dw} = Substrate ingestion rate (kg dry weight/day)
FIR_{dw} = Dry weight food ingestion rate (kg dry weight/day)
P_s = Percentage of dry food intake ingested as substrate

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As summarized in **Table 2**, average substrate ingestion, as a percentage of dry food intake, was identified for each receptor of concern based on literature sources. For receptors included in the derivation of Eco-SSLs, the average percentage of dry food intake was obtained from USEPA (2007a). For primarily piscivorous wildlife (mink and belted kingfisher), incidental substrate ingestion was assumed to be negligible, consistent with Sample and Suter (1994). For carnivorous mammals, including Canada lynx, grizzly bear, and North American wolverine, incidental substrate ingestion was assumed to not exceed the average incidental ingestion rate for the red fox reported in Beyer et al. (1994). No incidental substrate ingestion data were identified for the American dipper; therefore, a nominal incidental substrate ingestion rate of 1 percent of dry intake was assumed for American dipper (**Table 2**). However, based on the habitat preference of American dipper for fast-moving, clear streams with sand, pebble, or rocky stream bottoms, the assumption of 1 percent incidental substrate ingestion is likely conservative. Further evaluation of this assumption may be warranted in the BERA pending the potential influence of incidental sediment exposure in the risk characterization for American dipper.

For the deterministic exposure model, the receptor-specific SIR_{dw} will be estimated as a single point estimate based on the dry weight FIR_{dw} calculated using average BW and the average percentage of dry food intake as incidental substrate ingestion (**Table 2**).

For probabilistic exposure models, a distribution of potential SIRs will be developed for each receptor based on the distribution of FIR_{dw} described in the previous section. The distribution of SIRs will be developed based on randomly selected BW values used to develop the distribution of FIR_{dw}. For each randomly selected body weight, a corresponding SIR_{dw} will be calculated using the dry weight FIR_{dw} and the average percentage of dry food intake as incidental substrate ingestion. The receptor-specific distribution of SIRs is representative of the range of rates that may be observed within a given receptor population as a function of the potential range of body weights and corresponding food ingestion rates of individuals within that population.

Drinking Water Ingestion Rate

Drinking-water ingestion rates (WIRs) will also be derived based on an allometric relationships to body weight. For birds, Calder and Braun (1983) developed an equation for drinking-water ingestion based on a dataset representing 21 bird species with a body weights ranging from 0.011 to 3.15 kg, which encompasses the range of average avian body weights included in the exposure modeling for the Site (**Table 2**). WIRs for avian receptors will be estimated based on body weight as follows:

$$WIR_{avian} = 0.059 \times BW^{0.67} \qquad (5)$$

where:
WIR$_{avian}$ = Avian drinking water ingestion rate (L/day)
BW   = Receptor body weight (kg)

Drinking-water ingestion rates for mammalian receptors (WIR$_{mammalian}$) will be estimated based on an allometric relationship to body weight using an analogous equation from Calder and Braun (1983):

$$WIR_{mammalian} = 0.099 \times BW^{0.90} \qquad (6)$$

where:
WIR$_{mammalian}$ = Mammalian drinking-water ingestion rate (L/day)

BW   = Receptor body weight (kg)

Like other ingestion rates based on allometric relationships (e.g., FIR_{dw} and SIR_{dw}), estimates of WIR in deterministic exposure models will be based on arithmetic mean values of adult body weights reported in the literature or minimum body weights when arithmetic mean values are not available (**Table 2**). For probabilistic exposure models, WIRs will be calculated from randomly selected body weights used to develop the receptor-specific distributions of body weight, FIR_{dw}, and SIR_{dw}. Estimated WIRs calculated for each randomly selected body weight form a receptor-specific distribution that is representative of the range of drinking water rates that may be observed within a given receptor population, as a function of the potential range of body weights of individuals within that population.

Dietary Preference

Dietary models are developed to evaluate exposure to various trophic categories of wildlife based on typical feeding behaviors. Receptors select dietary items based on species-specific foraging strategies and behaviors, which are also influenced by the availability and abundance of dietary items within an exposure area. The relative compositions of prey items in the diets of wildlife receptors of concern will be estimated based on dietary studies obtained from the literature and summarized in compilations of exposure factors developed to support dietary exposure modeling (USEPA, 1993; USEPA, 2007a; USCHPPM, 2004; Sample and Suter, 1994).

Estimates of dietary composition in deterministic exposure models will be simplified initially to represent the predominant dietary items and/or more conservative exposure scenarios based on literature. A summary of the preliminary dietary compositions for the various receptors that will be evaluated in deterministic exposure models is presented in **Table 2**.

Probabilistic exposure estimates may consider the probability of a receptor selecting and ingesting a certain dietary item during foraging. USEPA (2003a) developed an algorithm to construct a unique and randomly selected diet for receptors based on a dietary matrix. A similar approach may be used to account for potential variability in dietary composition if probabilistic dietary exposure modeling is conducted in the BERA. If this approach is warranted, further documentation will be presented in the appendix describing the wildlife modeling procedures in the BERA Report.

Exposure Point Concentrations

Exposure variables refer to site-specific measurements, namely COPEC concentrations estimated in exposure media. The following sections describe the approach for defining EPCs for deterministic and probabilistic exposure modeling.

Deterministic Exposure Point Concentrations

EPCs to evaluate wildlife exposure in deterministic models in the BERA will be estimated for each exposure area using data collected as part of the Phase I and Phase II Site Characterization. EPCs will be calculated to represent a range of exposure scenarios:

- Maximum EPC: Represents a maximum exposure scenario based on the maximum measured concentration in each exposure area.

- Refined EPC: Represents the likely exposure to a conservative estimate of the mean concentrations at the site, assuming random foraging throughout each exposure area.

Refined EPCs for evaluating wildlife ingestion pathways will be calculated based on upper confidence limit of the mean (UCL_{mean}) COPEC concentrations. UCL_{mean} values represent a conservative estimate of average exposure conditions for a receptor foraging randomly over an exposure area. UCL_{mean} concentrations will be calculated using USEPA ProUCL software (version 5.1 or later) and the statistical approach will be consistent with USEPA ProUCL Version 5.1 Technical Guidance (USEPA, 2015). The UCL_{mean} calculation recommended in ProUCL will be used as the refined EPC in the risk estimate. Rationale for any deviations from the ProUCL-recommended UCL_{mean} calculation will be documented in the BERA Report.

In addition to UCL_{mean} EPCs, exposure will also be evaluated on a point-by-point basis for wildlife receptors with small home ranges (e.g., meadow vole, short-tailed shrew). Point-by-point comparisons will be conducted for COPECs with maximum EPCs resulting in EDDs that exceed TRV_{Low} doses. The evaluation of potential exposure on a point-by-point basis will support a spatial evaluation of areas where small home range receptors may be exposed to concentrations in soil that may result in adverse effects.

Consistent with the Phase I Site Characterization Sampling and Analysis Plan (SAP), EPCs will be calculated using incremental soil methodology (ISM) results to represent average exposure over the entire Operational Soil Area, as well as localized exposure within each individual decision unit (DU) within the Operational Soil Area (Roux Associates, 2015). EPCs for the entire Operational Soil area will represent potential exposure to ecological receptors with large home ranges and will be estimated based on UCL_{mean} concentrations of ISM samples from all DUs within an exposure area. Consistent with the Interstate Technology and Regulatory Council (ITRC) guidance (ITRC, 2012), UCL_{mean} concentrations to estimate EPCs for multiple DUs will be calculated using the Chebyshev UCL or Student's t UCL methods using the 95% UCL Calculator developed by the ITRC. EPCs within individual one-acre DUs will be estimated based on the ISM sample result to represent localized exposure to ecological receptors with small home ranges (i.e., less than one acre).

As indicated in the Phase II Site Characterization Sampling and Analysis Plan (Roux Associates, 2018), replicate ISM samples (r=3) will be collected from four DUs within the Operational Soil Area (approximately ten percent of the total number of DUs in the Operational Soil Area). Given that DUs in the Operational Soil Area have a similar conceptual site model, including similar soil type, site use/history, and expected contaminant types, ISM replicates from the four DUs will be used to provide an estimate of ISM sample variability within a DU. Estimates of ISM sample variability will be extrapolated to similar DUs without replicate ISM samples (similar to how laboratories use batch replicates for determining lab analysis precision). The extrapolation of estimated variability measured in DUs with ISM replication will be conducted in accordance with the guidance provided in ITRC (2012) based on an evaluation of ISM mean and variance estimates, including relative standard deviation (RSD)[2] and standard deviation, from the DUs with ISM replication.

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[2] Relative standard deviation (RSD) is calculated as the standard deviation divided by the arithmetic mean. RSD is also referred to as the coefficient of variation (CV).

The following sections discuss media-specific approaches for data compilation and pre-processing to support the estimation of EPCs.

Soil

Potential wildlife exposure via dietary ingestion pathways associated with surficial soils will be based on depth-weighted average concentrations of sampling intervals collected from 0-0.5 feet below ground surface (ft bgs) and 0.5-2.0 ft bgs to provide a representative EPC for each soil boring station. Depth-weighted average concentrations for the combined 0-2 ft bgs exposure interval will be calculated as follows:

$$C_{soil,0-2ft} = C_{soil,0-0.5ft} \times \frac{0.5ft}{2ft} + C_{soil,0.5-2ft} \times \frac{1.5ft}{2ft} \quad (7)$$

where:
$C_{soil,0-2ft}$ = Concentration in combined exposure interval starting from 0 to 2 ft bgs
$C_{soil,0-0.5ft}$ = Concentration in sampling interval starting from 0 to 0.5 ft bgs
$C_{soil,0.5-2ft}$ = Concentration in sampling interval starting from 0.5 to 2 ft bgs

As indicated in the BERA WP, sediment data from the 0 to 0.5 ft bgs sampling interval will be included in soil EPC calculations for transitional exposure areas that may be seasonally dry and provide habitat for terrestrial receptors. As described in the BERA WP, transitional exposure areas include (EHS Support, 2018):
- North Percolation Pond Area
- South Percolation Pond Area
- Cedar Creek Reservoir Overflow Ditch
- Northern Surface Water Feature

Sediment

EPCs for sediment in aquatic exposure areas will be calculated based on surficial samples collected from the 0 to 0.5 ft bgs (nominal) sampling interval. Preliminary EPCs will be based on the maximum measured concentration within an exposure area to represent the most conservative exposure scenario. Refined EPCs will include a conservative estimate of the central tendency of exposure (e.g., UCL$_{mean}$ concentration) to reflect the average dose that a receptor may experience while foraging randomly within an exposure area.

As indicated in the BERA WP, surficial soil data from the 0 to 0.5 ft bgs sampling interval will be included in sediment EPC calculations for transitional exposure areas that may be seasonally inundated and provide temporary aquatic habitat, in addition to terrestrial habitat. As described in the BERA WP, transitional exposure areas include (EHS Support, 2018):
- North Percolation Pond Area
- South Percolation Pond Area
- Cedar Creek Reservoir Overflow Ditch
- Northern Surface Water Feature

Surface Water

Relevant surface water sources that will be used as drinking water sources in the dietary exposure models for small-ranging (S) and long-ranging (L) terrestrial wildlife receptors are summarized below by terrestrial exposure area:

Exposure Area	Surface Water Source					
	Cedar Creek	Cedar Creek Reservoir Overflow	North Percolation Ponds	South Percolation Ponds	Flathead River	Northern Surface Water Feature
Eastern Undeveloped Area		S,L			L	
North-Central Undeveloped Area	L	S,L	S,L			S,L
Western Undeveloped Area	S,L	L	L			L
Central Landfill Area	L	S,L	S,L			L
Industrial Landfill Area	L	S,L	L			S,L
Main Plant Area	L	L	S,L			L
Flathead River Riparian Area				S,L	S,L	

S = Small-ranging receptors
L = Long-ranging receptors

For long-ranging receptors, potential drinking water sources will include an estimate of average exposure point concentrations (e.g., UCL_{mean}) from multiple surface water features that may be encountered while foraging. For receptors with small home ranges, surface water features within or adjacent to terrestrial exposure areas will be considered the primary drinking water source. It will be assumed that semi-aquatic wildlife receptors obtain drinking water from the aquatic or transitional exposure areas from which dietary and incidental ingestion exposure pathways are evaluated.

Surface water EPCs will be estimated based on COPEC concentrations measured in unfiltered surface water samples. Consistent with other exposure media, preliminary surface water EPCs will be estimated based on maximum COPEC concentrations and refined EPCs will be estimated on a conservative estimate of the central tendency of exposure (e.g., UCL_{mean} EPC concentration).

Probabilistic Exposure Point Concentrations

For probabilistic estimates, wildlife exposures will be evaluated based on the distribution of possible exposure concentrations, in contrast to the point estimate EPCs described above for deterministic models. Distributions of potential exposure concentrations will be developed in the statistical computing and graphics language R (R Core Team, 2013) based on the soil, sediment, and surface water datasets collected during Phase I and Phase II Site Characterization sampling, as described above for the estimation of deterministic EPCs. EPC distributions will represent the range of potential exposure concentrations that may be experienced by a given receptor foraging within exposure areas at the site.

The simulated exposure distributions may be truncated, as necessary, to exclude exposure concentrations that are not realistic (e.g., negative or extremely high concentrations). Potential truncation of the exposure distributions will be based on representative upper and lower tolerance limits of the measured concentrations in the site-specific datasets.

Terrestrial Bioaccumulation Relationships

Bioaccumulation of COPECs from soil into terrestrial dietary items, including vegetation, soil invertebrate tissue, and small mammal tissue will be estimated using soil EPCs described in the preceding section and terrestrial bioaccumulation factors (BAFs). BAFs are regression models or constant uptake factors that reflect the relationship between COPEC concentrations in dietary items and concentrations in soil. Differences in concentration are due to COPEC-specific properties that affect its tendency to bioaccumulate in tissue, balanced by the innate ability of the species to regulate body burden levels of the chemical via metabolic and excretory processes. Environmental conditions such as soil moisture, soil pH, and cation exchange capacities significantly influence whether soil COPECs remain bound in the soil matrix or can be mobilized (in a bioavailable form) and released for uptake.

The selection of appropriate BAFs is a critical component to dietary exposure modeling. General approaches for BAF selection have been discussed in Sample and Suter (1994) and USEPA (2007a). An approach that is consistent with these sources was followed in the selection of BAFs for the CFAC Site. The general hierarchy for selection of BAFs based on types of sources is as follows:
1. Use of regression equations derived from paired field- or laboratory-based measurements of COPEC concentrations in dietary items and soil
2. Ratio-derived BAFs developed based on paired data where the BAF is equal to the dietary tissue concentration divided by the soil concentration
3. Modeled equilibrium partitioning-derived BAFs based on physical or chemical characteristics
4. Assumptions based on values common to chemical class

The use of empirically derived BAF ratios is generally preferred over equilibrium partitioning-based BAFs, which are typically calculated based on factors such as log K_{ow} values, fraction of organic carbon in soil, and/or percent of lipids in invertebrates. Also, in selecting ratio-based BAFs, median values are generally preferred for use over maximum or other high-end BAFs (USEPA, 2007a).

Regression equations used to calculate COPEC concentrations in dietary items based on soil concentrations typically take the following form:

$$\ln C_j = B1 \times \ln C_{sub} + B0 \qquad (8)$$

where:
$\ln C_j$ = Natural log of the COPEC concentration in dietary item j
$\ln C_{sub}$ = Natural log COPEC concentration in substrate (e.g., soil)
$B1$ = Slope of the food/prey-soil regression
$B0$ = Intercept of the food/prey-soil regression

Ratio-derived BAFs can be generally presented as follows:

$$C_j = BAF \times C_{sub} \qquad\qquad (9)$$

where:

C_j = COPEC concentration in dietary item j (mg COPEC/kg tissue, dry weight)

C_{sub} = COPEC concentration in soil or sediment (mg COPEC/kg sediment or soil, dry weight)

BAF = Bioaccumulation factor developed based on paired empirical data where the BAF is equal to the dietary tissue concentration divided by the soil concentration (kg substrate/kg tissue, dry weight)

BAFs calculated based on equilibrium partitioning for non-ionic organic compounds are based on the log K_{ow} of the constituent:

$$\log BAF = B1 \times \log K_{ow} + B0 \qquad\qquad (10)$$

where:

BAF = Bioaccumulation factor

K_{ow} = Octanol-water partitioning coefficient

$B1$ = Slope of the BAF-log K_{ow} regression

$B0$ = Intercept of the BAF-log K_{ow} regression

BAFs calculated based on equilibrium partitioning are applied as ratio-based BAFs to estimate a dietary tissue concentration value. K_{ow} values to estimate BAFs based on equilibrium partitioning were obtained from USEPA Estimation Program Interface Suite K_{ow}Win v. 1.68 software program.

Finally, where ratio-based BAFs are not available and where no equilibrium partitioning method has been developed for calculating BAFs, other methods, such as using BAFs for chemicals within the same class and with similar structural properties, may be adopted as surrogate BAFs.

Terrestrial BAFs will be derived to estimate dry weight concentrations of dietary items, consistent with the reporting of soil COPEC concentrations in dry weight and the calculation of dry weight food ingestion rates FIR_{dw} (see Equation 1). **Table 3** presents a summary of the terrestrial BAFs that will be used to estimate COPEC uptake from soil into terrestrial dietary items, including plants, soil invertebrates, and small mammals. Estimated concentrations in terrestrial items are also presented based on example EPCs. The following sections discuss the basis for selecting terrestrial BAFs to represent uptake into each terrestrial dietary item.

Terrestrial Plants

The following sections provide the basis for estimating COPEC bioaccumulation from soil into terrestrial vegetation for major constituent groups. **Table 3** presents a summary of terrestrial plant BAFs and associated references.

Metals

Soil-to-plant bioaccumulation relationships for metals were primarily selected from literature sources adopted by USEPA in the derivation of Eco-SSLs (**Table 3**). Bioaccumulation relationships derived in

Bechtel-Jacobs (1998a) were the primary soil-to-plant uptake relationships adopted in the Eco-SSL development (USEPA, 2007a). Regression equations were used to estimate plant tissue concentrations for six metals based on relationships derived in Bechtel-Jacobs (1998a) and two metals based on relationships derived in USEPA (2007a). Slope and intercept values used in soil-to-plant regressions are provided in **Table 3**. Bioaccumulation factors were selected for other metals based on median BAFs derived in Bechtel-Jacobs (1998a) or soil-to-plant BAFs derived in Baes et al. (1984).

Other Inorganics

Soil-to-plant bioaccumulation data were limited for fluoride and cyanide (**Table 3**). A ratio-derived soil-to-plant BAF was identified for fluoride based on Baes et al. (1984). Based on Lanno and Menzie (2005), cyanide bioaccumulation into plant tissues was assumed to be negligible for soil uptake pathways. Bioaccumulation and trophic transfer via the food web is not considered to be a significant pathway for inorganic cyanide compounds (Lanno and Menzie, 2005).

Semi-Volatile Organic Compounds – Polycyclic Aromatic Hydrocarbons

Soil-to-plant bioaccumulation relationships for polycyclic aromatic hydrocarbons (PAHs) were selected based on relationships derived for low molecular weight (LMW) and high molecular weight (HMW) PAHs by USEPA in the derivation of Eco-SSLs (USEPA, 2007a). LMW PAHs typically have three or less condensed aromatic rings, while HMW PAHs have four or more aromatic rings. Acceptable compound-specific regression relationships were derived for LMW PAHs, except fluoranthene and naphthalene, and HMW PAHs, except benzo(b)fluoranthene, benzo(e)pyrene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene, and pyrene (**Table 3**). Slope and intercept values used in soil-to-plant regressions are provided in **Table 3**. For LMW and HMW PAHs without acceptable regression relationships, median ratio-derived BAFs were used to estimate soil-to-plant uptake (**Table 3**; USEPA, 2007a).

Volatile and Non-PAH Semi-Volatile Organic Compounds

Compound-specific soil-to-plant BAFs were not identified for methylcyclohexane, a volatile organic compound (VOC), or non-PAH semi-volatile organic compounds (SVOCs) identified as soil COPECs, except for pentachlorophenol (PCP). USEPA (2007a) recommends a median BAF from bioaccumulation data for PCP in plants of 5.93. For all other non-ionic compounds in this chemical class, the significant regression equation derived for rinsed plant foliage in USEPA (2007a) will be used to estimate the soil-to-plant BAF as a function of log K_{ow} based on the following relationship:

$$\log BAF = -0.4057 \times \log K_{ow} + 1.781 \qquad (11)$$

where:
BAF = Soil-plant BAF for non-ionic organic constituents
K_{ow} = Octanol-water partitioning coefficient

Compound-specific soil-to-plant BAF values derived from this relationship will be multiplied by the soil EPC to estimate the concentration of non-PAH SVOCs in terrestrial plant tissue (**Table 3**).

Dioxins/Furans

Chemical-specific soil to plant BAFs were not identified for dioxins/furans. Therefore, the regression equation for the uptake of non-ionic organic constituents from soil to rinsed foliage derived in USEPA (2007a) will be used to estimate uptake from soil to plant tissue for the dioxin/furan congeners identified as COPECs at the site (see Equation 11 above). The application of this regression relationship to estimate soil-to-plant BAFs for dioxin/furans is consistent with the approach used in the Los Alamos National Laboratory (LANL) EcoRisk Database, Release 4.1 (LANL, 2017).

Soil Invertebrates

The following sections provide the basis for estimating COPEC bioaccumulation from soil into soil invertebrate tissue for major constituent groups. **Table 3** presents a summary of soil invertebrate BAFs and associated references.

Metals

Soil-to-soil invertebrate bioaccumulation relationships for metals were primarily selected from literature sources adopted by USEPA in the derivation of Eco-SSLs (**Table 3**). Bioaccumulation relationships derived in Sample et al. (1998a) and Sample et al. (1999) were the primary soil-to-soil invertebrate uptake relationships adopted in the Eco-SSL development (USEPA, 2007a). Regression equations were used to estimate soil invertebrate tissue concentrations for six metals based on relationships derived in Sample et al. (1998a) and Sample et al. (1999). Slope and intercept values used in soil-to-soil invertebrate regressions are provided in **Table 3**. Ratio-derived bioaccumulation factors were selected for other metals based on median BAFs derived in Sample et al. (1998a). The median soil-to-insect BAF reported in USACHPPM (2004) was selected as the BAF for thallium (**Table 3**). Soil-to-soil invertebrate bioaccumulation data were not identified for antimony; therefore, a conservative default BAF of 1 was applied, consistent with USEPA (2007a).

Other Inorganics

Soil-to-soil invertebrate bioaccumulation data were limited for fluoride and cyanide (**Table 3**). A ratio-derived soil-to-plant BAF was identified for fluoride based on the median soil-to-insect BAF reported in USACHPPM (2004). Cyanide bioaccumulation into soil invertebrates was assumed to be negligible for soil uptake pathways, consistent with Lanno and Menzie (2005).

Semi-Volatile Organic Compounds — Polycyclic Aromatic Hydrocarbons

Soil-to-soil invertebrate BAFs for LMW and HMW PAHs were selected from BAFs derived using the partitioning model presented in USEPA (2007a). The model estimates the biota-to-soil water partitioning coefficient (K_{ww}) and divides it by the soil-to-water partitioning coefficient (K_d) to calculate the soil-to-earthworm BAF. USEPA (2007a) used soil organic carbon-to-water partitioning coefficient (K_{oc}) to calculate K_d using the class-specific models presented in Gerstl (1990). Further detail regarding the calculation of soil-to-earthworm BAFs for LMW and HMW PAHs is provided in Section 3.2.2 and Table 5 in USEPA (2007a). Ratio-based soil-to-earthworm BAF values derived in USEPA (2007a) using this

modeling approach will be multiplied by soil EPCs to estimate the concentrations of LMW and HMW PAHs in soil invertebrate tissues (**Table 3**).

Volatile and Non-PAH Semi-Volatile Organic Compounds

Compound-specific soil-to-soil invertebrate BAFs were not identified for methylcyclohexane or non-PAH SVOCs identified as soil COPECs, except for PCP. USEPA (2007a) developed a significant regression model to estimate PCP uptake into earthworms; however, the Eco-SSL calculated using this significant regression equation resulted in a soil concentration that was lower than the range of data used to derive the bioaccumulation regression relationship. Therefore, USEPA (2007a) applied a ratio-derived soil-to-earthworm BAF of 14.63 based on the median BAF from empirical studies to estimate soil-to-soil earthworm uptake of PCP. Consistent with USEPA (2007a), the median ratio-derived BAF will be used to estimate PCP concentrations in soil invertebrate tissue in the BERA (**Table 3**).

For other non-ionic compounds in this chemical class, the partitioning model approach applied by USEPA (2007) to estimate soil-to-soil invertebrate BAFs will be used to estimate soil-to-soil invertebrate BAFs in the BERA. Further detail regarding the approach for calculating soil-to-earthworm BAFs for non-ionic organic constituents is provided in Section 3.2.2 in USEPA (2007a). **Table 4** presents the calculations of soil-to-soil invertebrate BAFs for non-PAH SVOC COPECs in soil using the partitioning modeling approach.

Dioxins/Furans

Bioaccumulation of dioxin/furans from soil to earthworm tissues was estimated based on the relationship derived by Sample et al. (1998a):

$$\ln C_{invert} = 3.533 \times \ln C_{soil} + 1.182 \qquad (12)$$

where:
C_{invert} = Concentration in soil invertebrate (mg COPEC/kg tissue, dry weight)
C_{soil} = COPEC concentration in soil (mg COPEC/kg soil, dry weight)

Small Mammals

The following sections provide the basis for estimating COPEC bioaccumulation from soil into mammal tissue for major constituent groups. **Table 3** presents a summary of small mammal BAFs and associated references.

Metals

Soil-to-small mammal bioaccumulation relationships for metals were primarily selected from literature sources adopted by USEPA in the derivation of Eco-SSLs (**Table 3**). Bioaccumulation relationships derived in Sample et al. (1998b) and Baes et al. (1984) were the primary soil-to-small mammal uptake relationships adopted in the Eco-SSL development (USEPA, 2007a). As indicated in **Table 3**, significant regression equations were used to estimate soil invertebrate tissue concentrations for nine metals based on regressions derived in Sample et al. (1998b). Slope and intercept values used in soil-to-small

mammal regressions are provided in **Table 3**. A median ratio-derived soil-to-small mammal BAF was selected for mercury, consistent with LANL (2017).

Ratio-derived bioaccumulation factors were selected for antimony, barium, beryllium, and thallium based on diet-to-beef transfer factors reported in Baes et al. (1984). Consistent with USEPA (2007a), in the absence of alternative bioaccumulation relationships for metals, soil-to-beef transfer factors reported for metals in Baes et al. (1984) were used to estimate soil-to-small mammal BAFs based on the following:

$$BAF_{soil-mammal} = BAF_{soil-diet} \times 50 \times Tf_{diet-mammal} \qquad (13)$$

where:

$BAF_{soil-mammal}$ = Soil-to-small mammal BAF (kg soil/kg mammal tissue, dry weight)

$BAF_{soil-diet}$ = Soil-to-diet BAF; conservatively assumed to be a soil invertebrate diet (kg soil/kg tissue, dry weight)

$Tf_{diet-mammal}$ = Transfer factor from diet-to-mammal tissue (day/kg mammal tissue)

50 = Cattle food intake rate of 50 kg/day assumed by Baes et al. (1984)

Diet-to-beef transfer factors from Baes et al. (1984) for antimony, barium, beryllium, and thallium are provided in **Table 3**. Soil-to-small mammal BAF values derived using this approach will be multiplied by the soil EPC to estimate the concentration of these select metals in small mammal tissue (**Table 3**).

Other Inorganics

Soil-to-small mammal bioaccumulation data were limited for fluoride and cyanide (**Table 3**). Ratio-derived soil-to-small mammal BAFs were derived by LANL (2015) for fluoride; the LANL-derived soil-to-small mammal BAF values will be multiplied by soil EPCs to estimate the concentrations of fluoride in small mammal tissue (**Table 3**). Cyanide bioaccumulation into small mammals was assumed to be negligible for soil uptake pathways, consistent with Lanno and Menzie (2005).

Semi-Volatile Organic Compounds – Polycyclic Aromatic Hydrocarbons

Small mammal bioaccumulation data for LMW and HMW PAHs are limited. However, USEPA (2007a) assumes that PAH bioaccumulation is minimal due to the rapid metabolism of these compounds following ingestion by birds and mammals. Consistent with USEPA (2007a), the bioaccumulation of LMW and HMW PAHs in small mammal tissue is assumed to be negligible (**Table 3**).

Volatile and Non-PAH Semi-Volatile Organic Compounds

Compound-specific soil-to-small mammal bioaccumulation data were limited in general literature sources for methylcyclohexane and most non-PAH SVOC soil COPECs. USEPA (2007a) developed a general regression equation for the accumulation of PCP from the diet to chicken tissue; this relationship was assumed to be representative of potential accumulation from the diet to small mammal tissues (USEPA, 2007a). LANL (2015) calculated soil-to-small mammal BAFs for phthalates and hexachlorobenzene. These soil-to-small mammal tissue BAFs were also selected to represent potential bioaccumulation into small mammals at the Site (**Table 3**).

For methylcyclohexane and other non-PAH SVOCs, data for uptake from soil into small mammal tissue are lacking. For these constituents, the model used in the LANL (2017) EcoRisk food chain model to estimate the transfer factor for the flesh of prey items (TF_flesh_dw) will be used to estimate the BAF$_{soil-mammal}$ value in the BERA. The LANL (2017) model multiplies the uptake factor for beef/cattle, derived using the method recommended in EPA (2005j), by maximum ingestion rates and dietary BAFs of prey items consisting of other modeled receptors with lower trophic orders. To retain consistency with the LANL EcoRisk model, the same receptor species that were assumed in that model to be prey items for higher trophic order receptors were used to develop the CFAC BAFs (i.e., American robin, deer mouse, desert cottontail, and short-tailed shrew). The model equation is as follows:

$$BAF_{soil-mammal} = BAF_{beef} \times \left[\frac{(FIR_{MAX} \times BAF_{MAX\,Plant/Invert} + SIR_{MAX})}{(1-MC)}\right] \quad (14)$$

where:

$BAF_{soil-mammal}$	= Soil-to-small mammal BAF (kg soil/kg flesh, dry weight)
BAF_{beef}	= Diet-beef biotransfer factor (day/kg beef, wet weight)
FIR_{max}	= Maximum ingestion rate for prey species (kg food/day, dry weight)
$BAF_{MAX\,Plant/Invert}$	= Maximum BAF for plant or invertebrate dietary items of the prey species (kg soil, dry weight/kg tissue, wet weight)
$IR_{soilMAX}$	= Maximum ingestion rate of soil for prey species (kg soil/day, dry weight)
MC	= Moisture content of flesh (assumed 68 percent)

The biotransfer to beef factor is estimated using the following model described in Research Triangle Institute (RTI) (2005) and recommended by EPA (2005j):

$$\log BAF_{beef} = Fat_{beef} \times (-0.099 \times \log K_{ow}^2 + 1.07 \times \log K_{ow} - 3.56) \quad (15)$$

where:

BAF_{beef}	= Diet-beef biotransfer factor (day/kg beef, wet weight)
Fat_{beef}	= Fat content of beef; assumed to be 19 percent or 0.19 based on LANL (2017)
Kow	= Octanol-water partition coefficient

Table 5 presents calculated soil-to-small mammal BAFs estimated for methylcyclohexane and non-PAH SVOCs lacking soil-to-mammal BAFs from other literature sources.

Dioxins/Furans

Sample et al. (1998b) developed bioaccumulation relationships for estimating uptake of TCDD and tetrachlorinated dibenzofuran (TCDF) into small mammal tissue based on empirical data for multiple organism groups. A simple regression equation was recommended to estimate TCDD concentrations in small mammal tissue based on soil concentrations. A median ratio-derived soil-to-small mammal BAF was recommended to estimate TCDF concentrations in small mammal tissue. Consistent with the recommendations in Sample et al. (1998b), the simple regression equation will be used to estimate concentrations of TCDD and other dioxin congeners in small mammals; the median soil-to-small mammal BAF for TCDF will be used to estimate concentrations of TCDF and other furan congeners (**Table 3**).

Aquatic Bioaccumulation Relationships

The development of bioaccumulation relationships in aquatic environments will use similar approaches to those described in the preceding section for terrestrial environments. Bioaccumulation of COPECs from sediment or surface water into aquatic dietary items of semi-aquatic wildlife receptors, including benthic invertebrates and fish, will be estimated using the sediment EPCs and biota-sediment accumulation factors (BSAFs) or surface water EPCs and bioconcentration factors (BCFs). BSAFs or BCFs will be developed based on regression models or constant uptake factors that reflect the relationship between COPEC concentrations in dietary items and concentrations in sediment or surface water. Like BAFs for soil, the uptake of COPECs into biota within the aquatic environment is influenced by COPEC-specific properties, sediment characteristics (e.g., organic carbon content), receptor physiology, and the characteristics of dietary items (e.g., lipid content).

Table 5 presents a summary of the aquatic BSAFs or BCFs that will be used to estimate COPEC bioaccumulation from sediment or surface water into benthic invertebrates and fish. Estimated COPEC concentrations in aquatic biota are expressed on a dry weight basis based on BSAFs or BCFs derived on a dry weight basis. The following sections discuss the basis for selecting aquatic BSAFs or BCFs to represent uptake into each potential dietary item of semi-aquatic wildlife receptors of concern.

Benthic Invertebrates

Literature-based BSAFs or BCFs will be used to estimate the bioaccumulation of COPECs into benthic invertebrates as a function of sediment or surface water concentrations, respectively (**Table 5**). The following sections provide the basis for estimating COPEC bioaccumulation into benthic invertebrates for major constituent groups.

Metals

Metal concentrations in benthic invertebrates were estimated based on BSAFs presented in literature compilations (e.g., Sample et al., 1998b) and individual studies (**Table 5**). Median BSAF values provided in Sample et al. (1998b) were preferentially used to estimate benthic invertebrate concentrations for metals included in the compilation. For metals not included in Sample et al. (1998b), BSAF values were estimated from individual literature studies. The BSAF for aluminum was estimated as the ratio of mean oligochaete (*Lumbriculus variegatus*) tissue concentrations (dry weight) to mean whole sediment aluminum concentrations (dry weight) reported by Stanley et al. (2010). The median BSAF calculated from the ratios of mean benthic invertebrate tissue and mean whole sediment concentrations reported by Dovick et al. (2015) was used to estimate antimony bioaccumulation into benthic macroinvertebrates. Median BSAFs calculated from paired benthic invertebrate and sediment data reported by Hamilton et al. (2002) were used to estimate concentrations of barium, beryllium, selenium, and vanadium (**Table 5**). Sediment bioaccumulation data for thallium were limited; however, biomonitoring data from Turner et al. (2013) were used to estimate a BSAF for deposit-feeding invertebrates. In the absence of other data, a BSAF calculated as the mean concentration in deposit-feeding invertebrates and mean sediment concentration reported for the Plym estuary by Turner et al. (2013) was used as a BSAF for thallium (**Table 5**).

Other Inorganics

Bioaccumulation information for cyanide and fluoride was evaluated from literature reviews and primary literature. Based on Lanno and Menzie (2005), cyanide bioaccumulation into benthic invertebrates was assumed to be negligible for sediment and surface water uptake pathways. Bioaccumulation and trophic transfer via the food web is not considered to be a significant pathway for inorganic cyanide compounds (Lanno and Menzie, 2005).

Aqueous exposure to the fluoride ion (F^-) is the predominant bioaccumulation pathway for aquatic organisms. Given that aqueous exposure is the predominant bioaccumulation pathway, data reported by Aguirre-Sierra et al. (2013) were used to relate aqueous F^- concentrations to F^- concentrations in muscle tissue and exoskeleton of the freshwater white-clawed crayfish (*Austropotamobius pallipes*). As illustrated in Figure 1a, fluoride bioaccumulation in crayfish exoskeleton and muscle tissue increased exponentially from the control treatment (0.18 ± 0.07 mg/L) to the highest test treatment (84.8 ± 12.4 mg/L). Greater fluoride bioaccumulation was observed in the crayfish exoskeleton relative to muscle tissue, consistent with other studies that indicate greater accumulation in invertebrate exoskeletons (Sands et al. 1998; Camargo, 2003).

Based on the water-to-invertebrate relationships derived from Aguirre-Sierra et al. (2013), F^- concentrations in benthic invertebrate tissues will be estimated in the BERA as a function of F^- concentrations in unfiltered surface water using the relationship for crayfish muscle tissue (Figure 1a; **Table 5**):

$$C_{invertebrates} = 24.253 \times e^{(0.0773 \times C_{water})} \qquad (16)$$

where:

$C_{invertebrates}$ = Concentration in invertebrate tissue (mg F^-/kg dry weight)
C_{water} = Concentration in unfiltered surface water (mg F^-/L)

The crayfish muscle bioaccumulation relationship derived from data reported by Aguirre-Sierra et al. (2013) was selected to represent the more edible and digestible portions of crayfish tissue that may be consumed by wildlife. Further evaluation of this assumption may be warranted in the BERA pending an analysis of the potential influence of this uncertainty on the risk characterization of F- exposure to semi-aquatic wildlife.

Semi-Volatile Organic Compounds – Polycyclic Aromatic Hydrocarbons

PAH concentrations in benthic invertebrates were estimated based on the biota-sediment accumulation relationship described by DiToro and McGrath (2000) in the development of the target lipid model. BSAFs for PAH compounds were estimated on an organic carbon and lipid-normalized basis as a function of K_{ow}:

$$BSAF_{OC} = \frac{C_{lipid}}{C_{oc}} = K_{ow}^{-0.038} \qquad (17)$$

where:

$BSAF_{oc}$ = BSAF normalized by organism lipid content and sediment organic carbon content (kg organic carbon/kg lipid)

C_{lipid} = Tissue lipid concentration (mg PAH/kg lipid)
C_{oc} = Sediment organic carbon concentration (mg PAH/kg organic carbon)
K_{ow} = Octanol-water partitioning coefficient

Organic carbon and lipid-normalized BSAFs were estimated on a dry weight basis using assumed lipid and organic carbon content in sediments as follows:

$$BSAF_{dw} = BSAF_{oc} \times f_{lipid} \times \frac{1}{f_{oc}} \qquad (18)$$

where:
$BSAF_{dw}$ = BSAF specific to prey type and COPEC (kg sediment/kg tissue, dry weight)
$BSAF_{oc}$ = Organic carbon and lipid-normalized BSAF specific to prey type and COPEC (kg organic carbon/kg lipid)
f_{lipid} = Fraction of lipid in dietary items (0.065 assumed in **Table 5** for benthic invertebrates)
f_{oc} = Fraction of organic carbon in sediment (0.01 assumed in **Table 5**)

PAH-specific BASF$_{dw}$ values will be multiplied by the COPEC concentration in sediment (mg/kg dry weight) to estimate the COPEC concentration in the dietary item (mg/kg dry weight).

Semi-Volatile Organic Compounds – Non-Polycyclic Aromatic Hydrocarbon

Bioaccumulation of other non-ionic organic compounds was assumed to be similar to PAH bioaccumulation. Therefore, BSAFs for non-PAH SVOCs were estimated as a function of K_{ow} using the identical procedures described in the preceding section for PAHs (**Table 5**).

Fish

Literature-based BASFs or BCFs will be used to estimate the bioaccumulation of COPECs into fish tissue as a function of sediment or surface water concentrations, respectively (**Table 5**). The following sections provide the basis for estimating COPEC bioaccumulation into fish for major constituent groups.

Metals

Metal bioaccumulation into fish tissue was estimated based on the bioconcentration of metals from surface water into tissue. Sample et al. (1996b) was selected as a preferential source of BCFs based on a compilation of metal BCF values identified in the literature (**Table 5**). BCF values were not available in Sample et al. (1996b) for barium, silver, and vanadium; therefore, literature studies were reviewed to identify potential bioaccumulation relationships between surface water and fish tissue concentrations. A BCF of 74.4 for barium bioaccumulation into male fish carcass reported by Nakamoto and Hassler (1992) will be used to estimate barium concentrations in fish tissue. A BCF of 106 reported in study of silver bioaccumulation into Common Carp (*Cyprinus carpo*) will be used to estimate silver bioaccumulation into fish tissue (Laplace et al, 1992). CECBP (2008) compiled a range of BCF values from 365-630 for vanadium uptake into fish. Due to the paucity of data to support the calculation of a BCF for vanadium, the most conservative BCF value of 630 will be used to estimate fish tissue concentrations.

BCFs reported by Sample et al. (1996b) are based on wet weight fish tissue concentrations; therefore, BCF values were divided by 0.25 based on assumed percent solids of 25 percent to estimate fish tissue concentrations on a dry weight basis (**Table 5**). The BCF values for barium, silver, and vanadium were also divided by 0.25, based on BCFs being reported on a wet weight tissue basis.

Other Inorganics

Cyanide and fluoride bioaccumulation into fish tissue were evaluated based on literature reviews and primary literature studies. Consistent with Lanno and Menzie (2005), cyanide bioaccumulation into fish tissue was assumed to be negligible for sediment and surface water uptake pathways.

As previously stated for benthic invertebrates, aqueous exposure is the predominant F⁻ bioaccumulation pathway for aquatic organisms. Like invertebrates, F⁻ bioaccumulation in fish tends to be greatest in skeletal tissues, including bones, cartilage, and gills. Shi et al. (2009) evaluated the bioaccumulation of F⁻ from aqueous exposure into multiple tissue compartments in Siberian sturgeon (*Acipenser baerii*). As illustrated in Figure 1b, F⁻ concentrations increased in skeletal tissues (bone, cartilage, and gills) with increasing water concentrations ranging from the control treatment (0.26 ± 0.07 mg/L) to the highest test treatment (51.8 ± 3.5 mg/L). However, F⁻ concentrations in soft tissues, including skin, muscle, and viscera, generally remained unchanged with increasing aqueous exposure.

Based on the assumption that F⁻ concentrations in soft fish tissue, the more edible and digestible portions of fish for potential piscivorous consumers, will not exceed the concentrations in gill tissue, the bioaccumulation relationship derived using data from Shi et al. (2009) for gill tissue will be used as a conservative estimate of F⁻ concentrations in soft tissue compartments of fish (Figure 1b). F⁻ concentrations in fish tissue will be estimated in the BERA as a function of F⁻ concentrations in unfiltered surface water using the relationship derived for bioaccumulation into fish gills (**Table 5**):

$$C_{fish} = 42.377 \times \ln C_{water} + 214.34 \qquad (19)$$

where:

C_{fish} = Concentration in fish tissue (mg F⁻/kg dry weight)

C_{water} = Concentration in unfiltered surface water (mg F⁻/L)

The use of the fish gill bioaccumulation relationship derived from data presented in Shi et al. (2009) conservatively estimates F- concentrations in soft tissues that may be preferentially consumed by piscivorous wildlife receptors (e.g., mink) that typically forage on soft tissue (e.g., skin, muscle, and viscera) and forgo fish carcasses that contain mostly skeletal tissue. The use of this relationship also assumes that whole-body fish tissue concentrations will not exceed concentrations observed in fish gill tissue for those piscivorous wildlife that may consume the entire fish. Further evaluation of these assumptions may be warranted in the BERA pending the potential influence of this uncertainty on the risk characterization of F- exposure to semi-aquatic wildlife.

Semi-Volatile Organic Compounds — Polycyclic Aromatic Hydrocarbons

PAH concentrations in fish tissue were estimated based on the K_{ow}-based biota-sediment accumulation relationship used to estimate PAH concentrations in benthic invertebrates (DiToro and McGrath, 2000). Estimated concentrations were based on the equations presented in the preceding section for benthic

invertebrates and an assumed dry weight lipid fraction in fish of 0.085 (**Table 5**). The application of the BSAF relationship from DiToro, and McGrath (2000) conservatively assumes that exposure and uptake to fish within the water column does not exceed exposure and uptake in sediment and pore water within the benthic environment.

Semi-Volatile Organic Compounds – Non-Polycyclic Aromatic Hydrocarbons

Fish tissue concentrations of non-PAH SVOCs were estimated using the K_{ow}-based biota-sediment accumulation relationship used to estimate PAH concentrations in fish tissue, as described in the preceding section (DiToro and McGrath, 2000). Consistent with the approach for benthic invertebrates, this approach assumes that the bioaccumulation of other non-ionic organic compounds is a function of compound-specific K_{ow}, similar to PAHs.

Area Use Factors

In dietary exposure models, the AUF reflects the proportion of the dose that a receptor may obtain while foraging within the a given exposure area. The AUF is primarily estimated based on the ratio of the size of the exposure area to the area of the receptor foraging range. Species with very relatively small home ranges (e.g., meadow vole or short-tailed shrew) may forage entirely within the study area. However, for species with larger home ranges (e.g., large birds and mammals), most of the receptor diet may come from outside of an exposure area or the Site. If the foraging range of a receptor is greater than an exposure area, the EDD will be calculated as the sum of AUF-weighted doses obtained from the exposure areas within the typical home range of the receptor.

Available literature sources use various metrics to represent the size of the area used by a receptor: feeding or foraging radius, feeding or foraging distance, and home range or territory size, etc. In most cases, the size of the area used by a receptor for foraging and feeding is reported in acres and is referred to as the home range or territory. For initial exposure modeling, AUFs will be assigned a value of 1 (i.e., 100 percent foraging within the exposure area) and adjusted subsequently in the refined evaluation based on the corresponding sizes of the receptor-specific home range and the exposure area. Refined AUFs may also account for developed or unvegetated areas of the Site that do not provide habitat or forage base for wildlife receptors; these areas may be excluded from refined dietary exposure estimates due to the absence of forage base.

Seasonal use may also be considered in the calculation of the AUF to estimate the exposure duration for receptors that may only be present seasonally at the Site. Seasonal use will initially be assumed to be 100 percent; however, estimates of seasonal use may be incorporated into the AUF for the refined exposure evaluation in the BERA to address the potential uncertainty associated with the duration of exposure for seasonal receptors at the Site.

Toxicity Reference Values

TRVs will be derived to evaluate the potential for adverse ecological effects associated with the dietary doses estimated using the approaches described in the preceding sections. Two tiers of chronic TRVs

representing no-observed-adverse-effect levels (NOAELs) and LOAELs for growth and reproduction endpoints will be identified to evaluate the potential for adverse effects via wildlife ingestion pathways:

- Low TRV (TRV$_{Low}$): Represents the geometric mean NOAEL TRV identified in literature studies.
- High TRV (TRV$_{High}$): Represents a TRV-based on chronic exposure, that estimates a representative LOAEL in literature studies.

The two tiers of TRVs will be used to evaluate potential wildlife exposure based on EDDs calculated using preliminary and refined exposure assumptions and EPCs. For receptors with special regulatory status (i.e., threatened or endangered species), the TRV$_{Low}$ will be used to estimate the potential for adverse effects to potential individual receptors within the population.

Preliminary TRVs for bioaccumulative COPECs were identified from primarily peer-reviewed compilations of toxicity data for ecological risk assessment including:

- USEPA Eco-SSLs (USEPA, 2005a)
- LANL EcoRisk (LANL, 2017)
- ORNL *Toxicological Benchmarks for Wildlife: 1996 Revision* (Sample et al., 1996b)

At the request of USEPA, LOAELs provided in TechLaw (2008) and the approach used to derive TRVs in TechLaw (2008) were also considered in the selection of TRVs. For constituents lacking toxicity data from these compilations, literature sources were reviewed to identify appropriate TRVs. The following sections summarize the basis for selecting preliminary TRVs from literature/database sources for the BERA; a summary of the TRVs and associated sources is provided in **Table 6**. The BERA Report will also include an appendix that documents the basis for deriving final TRVs used in dietary exposure modeling.

Metals

Avian and mammalian TRVs for metals were selected primarily from TRVs used by the USEPA to develop Eco-SSLs or derived from studies accepted by the USEPA for Eco-SSL derivation (USEPA, 2005). The Eco-SSL approach generally adopted TRVs based on the geometric mean of NOAEL doses for growth and reproduction endpoints from accepted studies. However, in cases where the geometric mean of growth and reproduction NOAELs exceeded the lowest bounded LOAEL, the Eco-SSL conservatively selected the highest bounded NOAEL below the lowest bounded LOAEL for growth, reproduction, or survival as the preferred TRV. Other endpoints were considered for metals lacking data on growth, reproduction, or survival data.

Avian TRVs were identified for metal COPECs identified in the SLERA, except antimony and beryllium (**Table 6**). Most avian NOAEL TRVs for metals were obtained from the TRVs used by the USEPA to develop Eco-SSLs (**Table 6**); however, avian Eco-SSL TRVs were not available for mercury and thallium. Avian TRVs identified for mercury by Sample et al. (1996b) will be used as representative NOAEL and LOAEL TRVs in the BERA (**Table 6**). For thallium, avian NOAEL and LOAEL endpoints selected in the LANL EcoRisk database for the derivation of ecological screening levels (ESLs) were identified as preliminary TRVs for the BERA. Avian TRVs were not identified in the literature for antimony or beryllium; therefore, potential avian effects related to the estimated dietary exposure of these metals will be addressed as an uncertainty in the BERA.

Mammalian TRVs were selected primarily from TRVs used by the USEPA to develop Eco-SSLs or derived from studies accepted by the USEPA for Eco-SSL derivation (**Table 6**). NOAEL TRVs were selected based on TRVs used in the Eco-SSL derivation for metals, except for aluminum, mercury, and thallium. Consistent with USEPA (2003b), mammalian exposure to aluminum will be evaluated based on soil conditions, particularly pH, that control the mobility and bioavailability in soils (EHS Support, 2018). The NOAEL TRVs identified for mercury by Sample et al. (1996b) will be used as the representative NOAEL; however, a corresponding mammalian LOAEL was not identified for mercury (**Table 6**). For thallium, NOAEL and LOAEL endpoints were selected from the mammalian study selected in the LANL EcoRisk database (Formigli et al., 1986) for the derivation of ESLs.

Other Inorganics

Avian and mammalian TRVs for cyanide and fluoride were identified based on studies selected for use in calculating ESLs in the LANL EcoRisk Database (LANL, 2017; **Table 6**). For cyanide, an oral dosing study evaluating American kestrel (*Falco sparverius*) survival conducted by Wiemeyer et al. (1986) will be used as the basis for avian TRVs (**Table 6**). A chronic critical life stage study evaluating reproductive effects in rats conducted by Tewe and Maner (1981) will be used as the basis for mammalian TRVs for cyanide. For fluoride, a dietary study of reproductive effects of chronic-critical life stage exposure of Eastern screech owl (*Megascops asio*) conducted by Pattee et al. (1988) will be used as the basis of the avian NOAEL and LOAEL (**Table 6**). A chronic study evaluating potential reproductive effects of dietary fluorine in mink conducted by Aulerich et al. (1997) will be used the basis for the mammalian NOAEL and LOAEL (**Table 6**).

Semi-Volatile Organic Compounds – Polycyclic Aromatic Hydrocarbons

Consistent with USEPA (2007f), dietary exposure to LMW and HMW PAHs will be evaluated as an aggregate dose of each molecular weight group due to the common toxicological properties of PAH compounds within each group.

Avian toxicological studies for LMW and HMW are limited. USEPA (2007f) did not identify a sufficient number of acceptable studies to derive avian Eco-SSLs for either class of PAHs. Of the avian studies accepted by USEPA (2007f), the minimum NOAEL and LOAEL endpoints for growth reported by Trust et al. (1994) were selected as HMW PAH avian TRVs for the BERA (**Table 6**). For avian exposure to LMW PAHs, physiological endpoints from a chronic dietary exposure (7 months) to mallard duck reported by Patton and Dieter (1980) were selected as LMW PAH avian TRVs for the BERA (**Table 6**).

Mammalian NOAELs for LMW and HMW PAHs were selected based on TRVs used by USEPA in the derivation of Eco-SSLs (USEPA, 2007f). The mammalian NOAEL TRV for LMW PAHs was selected as the geometric mean of NOAELs for growth and reproduction endpoints (**Table 6**). The geometric mean of HMW PAH mammalian endpoints for growth and reproduction evaluated in Eco-SSL studies was 18 mg/kg-bw/day; however, the mammalian Eco-SSL for HMW PAH was conservatively derived based on the highest bounded NOAEL below the lowest bounded LOAEL for growth, reproduction, or survival (0.615 mg/kg-bw/day). The TRV of 0.615 mg/kg-bw/day used in the derivation of the mammalian Eco-SSL for HMW PAHs was conservatively selected as the HMW mammalian NOAEL for the BERA. However, given that this NOAEL TRV is two orders of magnitude below the geometric mean of mammalian growth and reproduction NOAELs for HMW PAHs in Eco-SSL studies, further evaluation of mammalian exposure

to HMW PAHs in the BERA will include consideration of the range of NOAEL endpoints for growth and survival. Mammalian LOAEL TRVs for LMW and HMW PAHs selected for the BERA are consistent with TechLaw (2008) based on the geometric mean of LOAEL endpoints for growth and reproduction (**Table 6**).

Semi-Volatile Organic Compounds – Non-Polycyclic Aromatic Hydrocarbons

Limited toxicological data are available for the development of TRVs for non-PAH SVOCs. Avian TRVs were identified in the LANL EcoRisk database (LANL, 2017), Sample et al. (1996b), and USEPA (2007g) for 4 of the 12 non-PAH SVOC COPECs, including two of the phthalate ester compounds, bis(2-ethylhexyl) phthalate and di-n-butyl phthalate (**Table 6**). Avian TRVs for di-n-butyl phthalate were selected as surrogate values that will be used to evaluate butyl benzylphthalate and di-n-octyl phthalate (**Table 6**). The avian NOAEL TRV for pentachlorophenol was selected consistent with USEPA (2007g); the LOAEL TRV for pentachlorophenol was estimated as the geometric mean of LOAEL endpoints for growth and reproduction, consistent with TechLaw (2008). No avian TRVs were identified for the remaining non-PAH SVOC COPECs (**Table 6**). Potential avian effects related to the estimated dietary exposure of these non-PAH SVOCs will be addressed as an uncertainty in the BERA.

Literature-based TRVs for mammalian receptors were identified for 7 of the 12 non-PAH SVOCs (**Table 6**). The selection of mammalian TRVs for non-PAH SVOCs was consistent with the value selected by LANL EcoRisk for bis(2-ethylhexyl) phthalate, butyl benzylphthalate, di-n-octyl phthalate, and hexachlorobenzene (**Table 6**). The mammalian NOAEL for pentachlorophenol was selected consistent with USEPA (2007g); the pentachlorophenol LOAEL was estimated as the geometric mean of LOAEL endpoints for growth and reproduction, consistent with TechLaw (2008). NOAEL and LOAEL endpoints reported by Kociba et al. (1977) in a chronic dietary study of Sprague-Dawley rats were selected as NOAEL and LOAEL TRVs for hexachlorobutadiene (**Table 6**). Sufficient information was not identified to develop TRVs for the remaining five SVOCs; mammalian dietary exposure to these non-PAH SVOCs will be addressed as an uncertainty in the BERA.

Dioxin/Furans

Dietary exposure to dioxin/furan compounds will be evaluated based on the potential additive toxicity of dioxin/furan compounds based on the toxicity equivalence methodology (USEPA, 2008a). A dietary dose will be calculated for the 17-individual dioxin/furan compounds in each sample. The EDD for each compound will be multiplied by the compound-specific TEF for birds or mammals to express the dose toxicity equivalence concentration (TEC) to the toxicity of TCDD. TECs of the 17 dioxin/furan compounds will be summed to calculate an overall TEC for comparison with dietary TRVs for 2,3,7,8-TCDD derived for birds and mammals.

Avian and mammalian TRVs for 2,3,7,8-TCDD were selected consistent with Sample et al. (1996b) and the LANL EcoRisk database (LANL, 2017), respectively (**Table 6**). Sample et al. (1996b) identified reproductive NOAEL and LOAEL endpoints (egg production and hatchability) for ring-necked pheasant in a study reported by Nosek et al. (1992). The LANL EcoRisk database selected mammalian NOAEL and LOAEL values based on chronic reproductive endpoints from a multi-generational study of Sprague-Dawley rats reported by Murray et al. (1979). NOAEL and LOAEL TRVs from these sources were selected to evaluate dietary TECs for avian and mammalian receptors of concern in the BERA (**Table 6**).

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Table 1
Summary of Bioaccumulative COPECs for Evaluation in Wildlife Exposure Modeling
Technical Memorandum: Proposed Wildlife Exposure Modeling Approach Columbia
Falls Aluminum Company
Columbia Falls, Montana

COPECs	log K$_{ow}$ USEPA EPISUITE	COPECs by Matrix			Bioaccumulative COPEC Lists				Wildlife Ingestion COPEC
		Soil	Sediment	Surface Water	log K$_{ow}$ > 3.5?	USEPA 2017 PBT Constituents	USEPA 2000 Important Bioaccumulative Constituents	USEPA Eco-SSL Wildlife Value	
Metals									
Aluminum	NA	•	•	•	NA			Narrative Statement	Yes
Antimony	NA	•	•		NA			Yes	Yes
Arsenic	NA	•	•		NA		Yes	Yes	Yes
Barium	NA	•	⊛	•	NA			Yes	Yes
Beryllium	NA	•	⊛		NA			Yes	Yes
Cadmium	NA	•	•	•	NA		Yes	Yes	Yes
Chromium	NA	•	•		NA		Yes	Yes	Yes
Cobalt	NA	•			NA			Yes	Yes
Copper	NA	•	•	•	NA		Yes	Yes	Yes
Lead	NA	•	•	•	NA	Yes	Yes	Yes	Yes
Manganese	NA	•		•	NA			Yes	Yes
Mercury	NA	•		•	NA	Yes	Yes	Yes	Yes
Nickel	NA	•	•	•	NA		Yes	Yes	Yes
Selenium	NA	•	•		NA		Yes	Yes	Yes
Silver	NA		•		NA		Yes	Yes	Yes
Thallium	NA	•			NA				Yes
Vanadium	NA	•	⊛		NA			Yes	Yes
Zinc	NA	•	•		NA		Yes	Yes	Yes
Other Inorganics									
Cyanide	NA	•	•	•	NA				Yes
Fluoride	NA	•		•	NA				Yes
Other Inorganics - Essential Nutrients									
Calcium	NA	•	⊛		NA				
Magnesium	NA	•			NA				
Potassium	NA	•			NA				
Sodium	NA	•			NA				
Polycyclic Aromatic Hydrocarbons (PAHs)									
Total HMW- PAHs	NA	•	•	•	NA	Yes	Yes	Yes	Yes
Total LMW- PAHs	NA	•	•	•	NA	Yes	Yes	Yes	Yes
Dioxin and Dioxin-Like Compounds									
Dioxin and Dioxin-Like Compounds	NA	•			NA	Yes	Yes		Yes
Non-PAH Semi-Volatile Organic Compounds (SVOCs)									
1,2,4,5-Tetrachlorobenzene	4.571	•			Yes		Yes		Yes
1,4-Dioxane	-0.320	•			No				
2,3,4,6-Tetrachlorophenol	4.090		•		Yes				Yes
2,4,5-Trichlorophenol	3.446	•	⊛		No				
2,4-Dimethylphenol	2.607	•			No				
2,4-Dinitrophenol	1.726	•			No				
2,4-Dinitrotoluene	2.176	•	⊛		No				
2,6-Dinitrotoluene	2.176	•	•		No				
2-Chloronaphthalene	3.814	•			Yes				Yes
2-Chlorophenol	2.157	⊛	•		No				
2-Methylphenol	2.060	•	•		No				
2-Nitrophenol	1.908	•			No				
3- and 4-methylphenol	2.060	⊛	⊛		No				
3,3'-Dichlorobenzidine	3.212	•			No				
4,6-Dinitro-2-methylphenol	2.273	•			No				
4-Chloroaniline	1.721	•			No				
4-Nitrophenol	1.908	•	•		No				
Acetophenone	1.670		⊛		No				
Benzaldehyde	1.710	⊛	⊛		No				
Bis(2-chloroethoxy)methane	1.295	•			No				
Bis(2-chloroethyl)ether	1.560		⊛		No				
Bis(2-ethylhexyl)phthalate	8.392	•	•		Yes				Yes
Butylbenzylphthalate	4.845	•			Yes				Yes
Caprolactam	0.660	⊛			No				
Carbazole	3.230		⊛		No				
Dibenzofuran	3.715	•	•		Yes				Yes
Di-n-butyl phthalate	4.610	•			Yes				Yes
Di-n-octyl phthalate	8.540	•			Yes				Yes
Hexachlorobenzene	5.860	•	•		Yes	Yes	Yes		Yes
Hexachlorobutadiene	4.717	•	•		Yes		Yes		Yes
Hexachlorocyclopentadiene	4.625	•			Yes		Yes		Yes
Hexachloroethane	4.035	•			Yes		Yes		Yes
Nitrobenzene	1.811	•			No				
N-Nitrosodi-n-propylamine	1.326	•			No				
N-Nitrosodiphenylamine	3.161	•			No				
Pentachlorophenol	4.735	•	•		Yes		Yes	Yes	Yes
Phenol	1.513	•	•		No				
Volatile Organic Compounds (VOCs)									
Bromomethane	1.180	⊛			No				
Cyclohexane	3.180	⊛			No				

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COPECs	log K$_{ow}$ USEPA EPISUITE	COPECs by Matrix			Bioaccumulative COPEC Lists				Wildlife Ingestion COPEC
		Soil	Sediment	Surface Water	log K$_{ow}$ > 3.5?	USEPA 2017 PBT Constituents	USEPA 2000 Important Bioaccumulative Constituents	USEPA Eco-SSL Wildlife Value	
Isopropylbenzene	3.450	⁂			No				
Methylacetate	0.370	⁂			No				
Methylcyclohexane	3.590	⁂			Yes				Yes
m,p-Xylene	3.090	⁂			No				
o-Xylene	3.090	⁂			No				

Notes:
COPEC, constituent of potential ecological concern
●, COPEC identified in the SLERA
⁂, COPEC identified in the BERA Work Plan as having a detection in at least one sample and had no associated ecological screening value.
USEPA, United States Environmental Protection Agency
PBT, persistent bioaccumulative toxic
Eco-SSL, ecological soil screening level
NA, not applicable
PAH, polycyclic aromatic hydrocarbons
SVOC, semi-volatile organic compounds
HMW, high molecular weight
LMW, low molecular weight

EHS Support

ED_002345C_00006500-00040

Table 2
Summary of Exposure Parameters for Wildlife Receptors of Concern
Technical Memorandum: Proposed Wildlife Exposure Modeling Approach
Columbia Falls Aluminum Company
Columbia Falls, Montana

| Representative Species | | | Foraging Range [a] | Foraging Range Reference | Body Weight (kg wet weight) | | | Dietary Composition | | | | | Ingestion Rates | | | | | | | |
Common Name	Scientific Name	Food-web classification			Mean	±SD	Body Weight Reference	Plant Material	Invertebrates	Fish	Small Mammals	Dietary Composition Reference	Dietary kg dry weight/day	Dietary Reference	Drinking Water L/day	Drinking Water Reference	Incidental Substrate Average % of Dry Intake	± SD % of Dry Intake	kg dry weight/day	Reference
Avian Receptors																				
American dipper	Cinclus mexicanus	semi-aquatic passerine invertivore	0.32 km	Bakus (1959)	0.0546	0.0048	Dunning (2008)		100%			Ealey (1977)	0.0091	Nagy (2001)[b]	0.0084	Calder and Braun (1983)	2%	---	0.0002	Assumption[l]
American woodock	Scolopax minor	small soil probing invertivore	11.1 ac	Gregg (1984); USACHPPM (2004)	0.176	---	Dunning (2008)	10%	90%			Sample and Suter (1994)	0.021	Nagy (2001)[b]	0.018	Calder and Braun (1983)	7.5%	6.9%	0.0016	USEPA (2007a)
Belted kingfisher	Ceryle alcyon	small aquatic piscivore	1.03 km	USACHPPM (2004)	0.148	0.0208	Dunning (2008)		10%	90%		Sample and Suter (1994)	0.023	Nagy (2001)[d]	0.016	Calder and Braun (1983)	0%	---	0	Sample and Suter (1994)[h]
Mourning dove	Zenaida macroura	small herbivore	1.6 km	Tomlinson et al. (1960)	0.115	0.0018	Dunning (2008)	100%				USEPA (2005a)	0.013	Nagy (2001)[c]	0.014	Calder and Braun (1983)	6.8%	5.3%	0.00089	USEPA (2007a)
Red-tailed hawk	Buteo jamaicensis	large carnivore	551 ac	Sample and Suter (1994)	1.028	---	Dunning (2008)				100%	Sample and Suter (1994)	0.084	Nagy (2001)[d]	0.060	Calder and Braun (1983)	2.6%	2.3%	0.0022	USEPA (2007a)
Yellow-billed Cuckoo	Coccyzus americanus	terrestrial insectivore (Special Status)	42 ac	USFWS (2017a)	0.064	0.0091	Dunning (2008)		100%			USEPA (1993)	0.010	Nagy (2001)[b]	0.0094	Calder and Braun (1983)	0%	---	0	Assumption[n]
Mammalian Receptors																				
Canada lynx	Lynx canadensis	medium carnivore (Special Status)	10,625 ac	USFWS (2017b)	6.0	---	USFWS (2017b)				100%	USFWS (2017b)	0.187	Nagy (2001)[e]	0.497	Calder and Braun (1983)	2.8%	0.08%	0.005	Beyer et al. (1994)[m]
Grizzly bear	Ursus arctos horribilis	large carnivore (Special Status)	32,000 ac	USFWS (2007)	90.7	---	USFWS (2007)	65%	15%	10%	10%	USFWS (2007), NPS (2018)	1.959	Nagy (2001)[e]	5.721	Calder and Braun (1983)	2.8%	0.08%	0.055	Beyer et al. (1994)[m]
Long-tailed weasel	Mustela frenata	small carnivore	12 ac	USACHPPM (2004)	0.153	0.003	Brown and Lasiewski (1972), as cited in USACHPPM (2004)				100%	USACHPPM (2004)	0.0079	Nagy (2001)[e]	0.018	Calder and Braun (1983)	1.6%	2.1%	0.0001	USEPA (2007a)
Meadow vole	Microtus pennsylvanicus	small terrestrial herbivore	0.13 ac	McCann (1976)[k]	0.033	0.0082	Brochu et al. (1988), as cited in USEPA (1993)	100%				USACHPPM (2004)	0.0050	Nagy (2001)[f]	0.005	Calder and Braun (1983)	1.3%	1.4%	0.00007	USEPA (2007a)
Mink	Mustela vison	medium semi-aquatic piscivore	1.85 km	Sample and Suter (1994)	0.550	---	Mitchell (1961), as cited in USEPA (1993)			100%		USEPA (1993); Sample and Suter (1994)	0.0238	Nagy (2001)[e]	0.058	Calder and Braun (1983)	0%	---	0	Sample and Suter (1994)
North American Wolverine	Gulo gulo luscus	medium carnivore (Special Status)	26000 ac	Montana Field Guide (2018)	8.0	---	USFWS (2018)				100%	Lofroth et al. (2007)	0.240	Nagy (2001)[e]	0.643	Calder and Braun (1983)	2.8%	0.08%	0.007	Beyer et al. (1994)[m]
Short-tailed shrew	Blarina brevicauda	small terrestrial invertivore	1 ac	Sample and Suter (1994)	0.015	0.00078	Schlessinger and Potter (1974), as cited in Sample and Suter (1994)		100%			Sample and Suter (1994)	0.002	Nagy (2001)[g]	0.002	Calder and Braun (1983)	1.1%	1.5%	0.00002	USEPA (2007a)

Notes:
a, ac, acres; km, kilometers
b, Estimated food ingestion rate (kg/day dry weight) for insectivorous birds = $(0.54[Body Weight in grams]^{0.705})/1000$ (Nagy 2001);
c, Estimated food ingestion rate (kg/day dry weight) for omnivorous birds = $(0.670[Body Weight in grams]^{0.627})/1000$ (Nagy 2001);
d, Estimated food ingestion rate (kg/day dry weight) for carnivorous birds = $(0.849[Body Weight in grams]^{0.663})/1000$ (Nagy 2001);
e, Estimated food ingestion rate (kg/day dry weight) for Carnivora = $(0.102[Body Weight in grams]^{0.864})/1000$ (Nagy 2001);
f, Estimated food ingestion rate (kg/day dry weight) for Rodentia = $(0.332[Body Weight in grams]^{0.774})/1000$ (Nagy 2001);
g, Estimated food ingestion rate (kg/day dry weight) for insectivorous mammals = $(0.373[Body Weight in grams]^{0.622})/1000$ (Nagy 2001);
h, Based on assumption from Sample and Suter 1994 that substrate ingestion is neglible for piscivores;
i, Estimated drinking water ingestion rate for birds = $(0.059×[body weight in kg]BW^{0.67}$ (Caulder and Braun, 1983)
j, Estimated drinking water ingestion rate for mammals = $(0.099×[body weight in kg]BW^{0.90}$ (Caulder and Braun, 1983)
k, As cited in the Montana Field Guide, accessed at http://fieldguide.mt.gov/default.aspx
l, Literature-based incidental substrate ingestion rate was not identified; assumed limited incidental ingestion based on habitat preference for fast-moving, clear streams with sand, pebble, or rocky stream bottoms.
m, Based on red fox soil ingestion rate assuming the soil ingestion rate of top predators does not exceed the soil ingestion rate of red fox.
SD, standard deviation

EHS Support

Analyte	log K_{ow}	Maximum Soil Exposure Point Concentration (mg/kg, dry weight)	Estimated Concentrations in Dietary Items of Terrestrial Receptors (mg/kg, dry weight)								
			Plants			Soil Invertebrates			Small Mammals		
			Bioaccumulation Factor (BAF)	Estimated Concentration	BAF Reference	Bioaccumulation Factor (BAF)	Estimated Concentration	BAF Reference	Bioaccumulation Factor (BAF)	Estimated Concentration	BAF Reference
Inorganics - Metals											
Aluminum	NA	10.0	8.00E-04	8.0E-03	Baes et al. (1984)	5.3E-02	5.3E-01	Sample et al. (1998a)	6.0E-06	6.0E-05	Baes et al. (1984)[e]
Antimony	NA	10.0	Regression[a]	3.42E-01	USEPA (2007a)	1.0E+00	1.0E+01	Assumption[c]	5.0E-02	5.00E-01	Baes et al. (1984)[e]
Arsenic	NA	10.0	3.75E-02	3.8E-01	Bechtel-Jacobs (1998a)[f]	Regression[d]	1.23E+00	Sample et al. (1999)	Regression[g]	5.17E-02	Sample et al. (1998b)
Barium	NA	10.0	1.56E-01	1.6E+00	Bechtel-Jacobs (1998a)[f]	9.100E-02	9.1E-01	Sample et al. (1998a)	6.8E-04	6.83E-03	Baes et al. (1984)[e]
Beryllium	NA	10.0	Regression[a]	3.17E+00	USEPA (2007a)	4.5E-02	4.5E-01	Sample et al. (1998a)	2.3E-03	2.25E-02	Baes et al. (1984)[e]
Cadmium	NA	10.0	Regression[a]	2.19E+00	Bechtel-Jacobs (1998a)	Regression[d]	5.17E+01	Sample et al. (1999)	Regression[g]	8.44E-01	Sample et al. (1998b)
Chromium	NA	10.0	4.10E-02	4.1E-01	Bechtel-Jacobs (1998a)[f]	3.1E-01	3.1E+00	Sample et al. (1998a)	Regression[g]	1.26E+00	Sample et al. (1998b)
Cobalt	NA	10.0	7.50E-03	7.5E-02	Bechtel-Jacobs (1998a)[f]	1.2E-01	1.2E+00	Sample et al. (1998a)	Regression[g]	2.33E-01	Sample et al. (1998b)
Copper	NA	10.0	Regression[a]	1.27E+00	Bechtel-Jacobs (1998a)	5.2E-01	5.2E+00	Sample et al. (1998a)	Regression[g]	1.07E+01	Sample et al. (1998b)
Lead	NA	10.0	Regression[a]	9.64E-01	Bechtel-Jacobs (1998a)	Regression[d]	5.16E+00	Sample et al. (1999)	Regression[g]	2.99E+00	Sample et al. (1998b)
Manganese	NA	10.0	7.90E-02	7.9E-01	Bechtel-Jacobs (1998a)[f]	Regression[d]	2.14E+00	Sample et al. (1999)	2.1E-02	2.1E-01	Sample et al. (1998b)[k]
Mercury	NA	10.0	Regression[a]	1.74E-01	Bechtel-Jacobs (1998a)	3.9E+00	3.9E+01	Sample et al. (1998a)	3.8E-01	3.8E+00	LANL (2015)
Nickel	NA	10.0	Regression[a]	6.06E-01	Bechtel-Jacobs (1998a)	7.8E-01	7.8E+00	Sample et al. (1998a)	Regression[g]	2.28E+00	Sample et al. (1998b)
Selenium	NA	10.0	Regression[a]	6.46E+00	Bechtel-Jacobs (1998a)	Regression[d]	5.02E+00	Sample et al. (1998a)	Regression[g]	1.57E+00	Sample et al. (1998b)
Thallium	NA	10.0	4.00E-03	4.0E-02	Baes et al. (1984)	5.4E-02	5.4E-01	USCHPPM (2004)	1.1E-01	1.08E+00	Baes et al. (1984)[e]
Vanadium	NA	10.0	4.85E-03	4.9E-02	Bechtel-Jacobs (1998a)[f]	4.2E-02	4.2E-01	Sample et al. (1998a)	1.2E-02	1.2E-01	Sample et al. (1998b)[k]
Zinc	NA	10.0	Regression[a]	1.73E+01	Bechtel-Jacobs (1998a)	Regression[d]	1.82E+02	Sample et al. (1998a)	Regression[g]	9.24E+01	Sample et al. (1998b)
Inorganics - Other Inorganics											
Cyanide	NA	10.0	0.00E+00	0.0E+00	Lanno and Menzie (2005)	0.00E+00	0.0E+00	Lanno and Menzie (2005)	0.0E+00	0.0E+00	Lanno and Menzie (2005)
Fluoride	NA	10.0	6.00E-02	6.0E-01	Baes et al. (1984)	1.2E-01	1.2E+00	USCHPPM (2004)	1.6E-02	1.6E-01	LANL (2015)
Semi-volatile Organic Compounds (SVOCs) - Polycyclic Aromatic Hydrocarbons (PAHs)											
Low Molecular Weight (LMW) PAHs:											
Acenaphthene	3.92	10.0	Regression[a]	5.4E-04	USEPA (2007a)	1.47E+00	1.47E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Acenaphthylene	4.07	10.0	Regression[a]	2.0E+00	USEPA (2007a)	2.29E+01	2.29E+02	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Anthracene	4.55	10.0	Regression[a]	2.2E+00	USEPA (2007a)	2.42E+00	2.42E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Fluorene	4.18	10.0	Regression[a]	5.4E-04	USEPA (2007a)	9.57E+00	9.57E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Naphthalene	3.36	10.0	1.22E+01	1.2E+02	USEPA (2007a)	4.40E+00	4.40E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Phenanthrene	4.55	10.0	Regression[a]	3.5E+00	USEPA (2007a)	1.72E+00	1.72E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
High Molecular Weight (HMW) PAHs:											
Benzo(a)anthracene	5.7	10.0	Regression[a]	2.6E-01	USEPA (2007a)	1.59E+00	1.59E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Benzo[A]Pyrene	6.11	10.0	Regression[a]	1.2E+00	USEPA (2007a)	1.33E+00	1.33E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Benzo(b)fluoranthene	6.2	10.0	3.10E-01	3.1E+00	USEPA (2007a)	2.60E+00	2.60E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Benzo(g,h,i)perylene	6.7	10.0	Regression[a]	6.0E+00	USEPA (2007a)	2.94E+00	2.94E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Benzo(k)fluoranthene	6.2	10.0	Regression[a]	8.4E-01	USEPA (2007a)	2.60E+00	2.60E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Chrysene	5.7	10.0	Regression[a]	2.6E-01	USEPA (2007a)	2.29E+00	2.29E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]

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Analyte	log K_{ow}	Maximum Soil Exposure Point Concentration (mg/kg, dry weight)	Estimated Concentrations in Dietary Items of Terrestrial Receptors (mg/kg, dry weight)								
			Plants			Soil Invertebrates			Small Mammals		
			Bioaccumulation Factor (BAF)	Estimated Concentration	BAF Reference	Bioaccumulation Factor (BAF)	Estimated Concentration	BAF Reference	Bioaccumulation Factor (BAF)	Estimated Concentration	BAF Reference
Dibenz(a,h)anthracene	6.69	10.0	1.30E-01	1.3E+00	USEPA (2007a)	2.31E+00	2.31E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Fluoranthene	4.95	10.0	5.00E-01	5.0E+00	USEPA (2007a)	3.04E+00	3.04E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Indeno (1,2,3-CD) Pyrene	6.58	10.0	1.10E-01	1.1E+00	USEPA (2007a)	2.86E+00	2.86E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Pyrene	4.88	10.0	7.20E-01	7.2E+00	USEPA (2007a)	1.75E+00	1.75E+01	USEPA (2007a)	0.0E+00	0.0E+00	USEPA (2007a)[i]
Semi-volatile Organic Compounds (SVOCs) - Non-PAH SVOCs											
Bis(2-ethylhexyl)phthalate	8.39	10.0	2.38E-02	2.4E-01	USEPA (2007a)	5.4E+01	5.4E+02	USEPA (2007a)	7.8E-01	7.8E+00	LANL (2015)
Butylbenzylphthalate	4.84	10.0	6.54E-01	6.5E+00	USEPA (2007a)	1.1E+01	1.1E+02	USEPA (2007a)	1.2E-01	1.2E+00	LANL (2015)
Dibenzofuran	3.71	10.0	1.88E+00	1.9E+01	USEPA (2007a)	7.0E+00	7.0E+01	USEPA (2007a)	5.60E-02	5.6E-01	Calculated[k]
Di-n-butyl phthalate	4.61	10.0	8.14E-01	8.1E+00	USEPA (2007a)	1.0E+01	1.0E+02	USEPA (2007a)	4.5E-01	4.5E+00	LANL (2015)
Hexachlorobenzene	5.86	10.0	2.53E-01	2.5E+00	USEPA (2007a)	1.8E+01	1.8E+02	USEPA (2007a)	2.7E+00	2.7E+01	LANL (2015)
Pentachlorophenol	4.74	10.0	5.93E+00	5.9E+01	USEPA (2007a)	1.5E+01	1.5E+02	USEPA (2007a)	Regression[h]	8.6E-01	USEPA (2007a)
1,2,4,5-Tetrachlorobenzene	4.57	10.0	8.44E-01	8.4E+00	USEPA (2007a)	1.0E+01	1.0E+02	USEPA (2007a)	1.3E-01	1.3E+00	Calculated[k]
2-Chloronaphthalene	3.81	10.0	1.71E+00	1.7E+01	USEPA (2007a)	7.3E+00	7.3E+01	USEPA (2007a)	6.3E-02	6.3E-01	Calculated[k]
Di-n-octyl phthalate	8.54	10.0	2.07E-02	2.1E-01	USEPA (2007a)	5.8E+01	5.8E+02	USEPA (2007a)	1.0E+00	1.0E+01	LANL (2015)
Hexachlorobutadiene	4.72	10.0	7.37E-01	7.4E+00	USEPA (2007a)	1.1E+01	1.1E+02	USEPA (2007a)	1.5E-01	1.5E+00	Calculated[k]
Hexachlorocyclopentadiene	4.63	10.0	8.03E-01	8.0E+00	USEPA (2007a)	1.0E+01	1.0E+02	USEPA (2007a)	1.4E-01	1.4E+00	Calculated[k]
Hexachloroethane	4.03	10.0	1.39E+00	1.4E+01	USEPA (2007a)	8.0E+00	8.0E+01	USEPA (2007a)	8.1E-02	8.1E-01	Calculated[k]
Volatile Organic Compounds (VOCs)											
Methylcyclohexane	3.59	10.0	2.11E+00	2.1E+01	USEPA (2007a)	6.6E+00	6.6E+01	USEPA (2007a)	7.8E-01	7.8E+00	LANL (2015)
Dioxin/Furans											
2,3,7,8-TCDD	6.92	0.000001	9.41E-02	9.4E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	Regression[g]	5.7E-07	Sample et al. (1998b)
1,2,3,7,8-PeCDD	7.56	0.000001	5.17E-02	5.2E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	Regression[g]	5.7E-07	Sample et al. (1998b)
1,2,3,4,7,8-HxCDD	8.21	0.000001	2.82E-02	2.8E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	Regression[g]	5.7E-07	Sample et al. (1998b)
1,2,3,6,7,8-HxCDD	8.21	0.000001	2.82E-02	2.8E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	Regression[g]	5.7E-07	Sample et al. (1998b)
1,2,3,7,8,9-HxCDD	8.21	0.000001	2.82E-02	2.8E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	Regression[g]	5.7E-07	Sample et al. (1998b)
1,2,3,4,6,7,8-HpCDD	8.85	0.000001	1.55E-02	1.6E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	Regression[g]	5.7E-07	Sample et al. (1998b)
OCDD	9.50	0.000001	8.45E-03	8.4E-09	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	Regression[g]	5.7E-07	Sample et al. (1998b)
2,3,7,8-TCDF	6.29	0.000001	1.69E-01	1.7E-07	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	1.3E-01	1.3E-07	Sample et al. (1998b)[j]
1,2,3,7,8-PeCDF	6.94	0.000001	9.24E-02	9.2E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	1.3E-01	1.3E-07	Sample et al. (1998b)[j]
2,3,4,7,8-PeCDF	6.94	0.000001	9.24E-02	9.2E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	1.3E-01	1.3E-07	Sample et al. (1998b)[j]
1,2,3,4,7,8-HxCDF	7.92	0.000001	3.70E-02	3.7E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	1.3E-01	1.3E-07	Sample et al. (1998b)[j]
1,2,3,6,7,8-HxCDF	7.92	0.000001	3.70E-02	3.7E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	1.3E-01	1.3E-07	Sample et al. (1998b)[j]
2,3,4,6,7,8-HxCDF	7.92	0.000001	3.70E-02	3.7E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	1.3E-01	1.3E-07	Sample et al. (1998b)[j]
1,2,3,7,8,9-HxCDF	7.58	0.000001	5.08E-02	5.1E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	1.3E-01	1.3E-07	Sample et al. (1998b)[j]
1,2,3,4,6,7,8-HpCDF	8.23	0.000001	2.77E-02	2.8E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	1.3E-01	1.3E-07	Sample et al. (1998b)[j]
1,2,3,4,7,8,9-HpCDF	8.23	0.000001	2.77E-02	2.8E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	1.3E-01	1.3E-07	Sample et al. (1998b)[j]
OCDF	8.87	0.000001	1.52E-02	1.5E-08	USEPA (2007a)[b]	Regression[d]	2.8E-06	Sample et al. (1998a)	1.3E-01	1.3E-07	Sample et al. (1998b)[j]

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Notes:

Maximum soil exposure point concentrations are example values to illustrate the calculation of COPEC concentrations in tissue; these values are not representative of exposure concentrations at the Site.

a, Plant tissue concentrations (mg/kg dry weight) calculated based on regression models, where ln([tissue]) = B0 + B1(ln[soil]). Slopes (B1) and intercepts (B0) are as follows:

Analyte	B0	B1	Data Source
Antimony	-3.233	0.938	USEPA (2007)
Beryllium	-0.5361	0.7345	USEPA (2007)
Cadmium	-0.475	0.546	Bechtel-Jacobs (1998)
Copper	0.668	0.394	Bechtel-Jacobs (1998)
Lead	-1.328	0.561	Bechtel-Jacobs (1998)
Mercury	0.544	-0.996	Bechtel-Jacobs (1998)
Nickel	-2.223	0.748	Bechtel-Jacobs (1998)
Selenium	-0.677	1.104	Bechtel-Jacobs (1998)
Zinc	1.575	0.554	Bechtel-Jacobs (1998)
Acenaphthene	-5.562	-0.8556	USEPA (2007a)
Acenaphthylene	-1.144	0.791	USEPA (2007a)
Anthracene	-0.9887	0.7784	USEPA (2007a)
Benzo(a)anthracene	-2.7078	0.5944	USEPA (2007a)
Benzo(a)pyrene	-2.0615	0.975	USEPA (2007a)
Benzo(g,h,i)perylene	-0.9313	1.1829	USEPA (2007a)
Benzo(k)fluoranthene	-2.1579	0.8595	USEPA (2007a)
Chrysene	-2.7078	0.5944	USEPA (2007a)
Fluorene	-5.562	-0.8556	USEPA (2007a)
Phenanthrene	-0.1665	0.6203	USEPA (2007a)

b, Soil-to-plant BAF based on K_{ow} model for non-ionic organic compounds (rinsed foliage data) provided in USEPA (2005), where: log BAF = -0.4057(log K_{ow}) + 1.781; log K_{ow} values obtained from USEPA EpiSuite V. 1.69, KOWWIN module.

c, Soil-invertebrate bioaccumulation factor could not be identified; therefore, a conservative default accumulation factor of 1.0 was assumed.

d, Soil invertebrate tissue concentrations (mg/kg dry weight) calculated based on regression models, where ln([tissue]) = B0 + B1(ln[soil]) and slopes (B1) and intercepts (B0) are as follows:

Analyte	B0	B1	Data Source
Arsenic	-1.421	0.706	Sample et al. (1999)
Cadmium	2.114	0.795	Sample et al. (1999)
Lead	-0.218	0.807	Sample et al. (1999)
Manganese	-0.809	0.682	Sample et al. (1999)
Selenium	-0.075	0.733	Sample et al. (1999)
Zinc	4.449	0.328	Sample et al. (1999)
2,3,7,8-TCDD	3.533	1.182	Sample et al. (1998a)

e, Bioaccumulation factor estimated as the product of the soil-plant and ingestion-beef factors reported in Baes et al. (1984)

f, Median soil-to-plant uptake factors reported in Bechtel-Jacobs (1998) were used as bioaccumulation factors.

g, Small mammal tissue concentrations (mg/kg dry weight) calculated based on regression models, where ln([tissue]) = B0 + B1(ln[soil]) and slopes (B1) and intercepts (B0) are as follows:

Analyte	B0	B1	Data Source
Arsenic	-4.8471	0.8188	Sample et al. (1998b)
Cadmium	-1.2571	0.4723	Sample et al. (1998b)
Chromium	-1.4599	0.7338	Sample et al. (1998b)
Cobalt	-4.4669	1.307	Sample et al. (1998b)
Copper	2.042	0.144	Sample et al. (1998b)
Lead	0.0761	0.4422	Sample et al. (1998b)
Nickel	-0.2462	0.4658	Sample et al. (1998b)
Selenium	-0.4158	0.3764	Sample et al. (1998b)
Zinc	4.3632	0.0706	Sample et al. (1998b)
2,3,7,8-TCDD	0.8113	1.0993	Sample et al. (1998b)

h, Pentachlorophenol concentration in small mammal tissue (mg/kg dry weight) calculated based on regression models, where [tissue] = 0.198 + 0.00452([diet$_{invertebrate}$])

i, USEPA (2005) assumes bioaccumulation of PAHs by birds and mammals is minimal due to rapid metabolism of these compounds after ingestion.

j, Small mammal tissue estimated based on the medial BAF for the general model presented in Sample et al. (1998b)

k, No value was identified in the literature; soil-to-small mammal BAF estimated based on the approach presented in Table 5, consistent with LANL (2017)

Table 4
Estimated Soil to Earthworm Bioaccumulation Factors (BAF) for Non-Ionic Organic Compounds
Technical Memorandum: Proposed Wildlife Exposure Modeling Approach
Columbia Falls Aluminum Company
Columbia Falls, Montana

Analyte	K_{ow}: Octanol to water partitioning coefficient log K_{ow} [f]	K_{ww}: worm to soil water partitioning coefficient			K_{oc}: water to soil organic carbon partioning coefficient [c]				K_d: soil to water partitioning coefficient [d]	Soil to Earthworm BAF [e]
		log K_{ww} [a]	K_{ww} wet (L/kg worm ww)	K_{ww} dry (L/kg worm dw) [b]	slope	intercept	log K_{oc}	K_{oc}	K_d (L/kg soil dw)	
Bis(2-ethylhexyl)phthalate	8.39	5.30	2.00E+05	1.25E+06	6.79E-01	6.63E-01	6.36E+00	2.30E+06	2.30E+04	**5.44E+01**
Butylbenzylphthalate	4.84	2.21	1.64E+02	1.02E+03	6.79E-01	6.63E-01	3.95E+00	8.96E+03	8.96E+01	**1.14E+01**
Dibenzofuran	3.71	1.23	1.71E+01	1.07E+02	6.79E-01	6.63E-01	3.19E+00	1.53E+03	1.53E+01	**6.96E+00**
Di-n-butyl phthalate	4.61	2.01	1.02E+02	6.41E+02	6.79E-01	6.63E-01	3.79E+00	6.21E+03	6.21E+01	**1.03E+01**
Hexachlorobenzene	5.86	3.10	1.25E+03	7.84E+03	6.79E-01	6.63E-01	4.64E+00	4.38E+04	4.38E+02	**1.79E+01**
Pentachlorophenol	4.74	2.12	1.32E+02	8.23E+02	6.79E-01	6.63E-01	3.88E+00	7.56E+03	7.56E+01	**1.09E+01**
1,2,4,5-Tetrachlorobenzene	4.57	1.98	9.48E+01	5.92E+02	6.79E-01	6.63E-01	3.77E+00	5.84E+03	5.84E+01	**1.01E+01**
2-Chloronaphthalene	3.81	1.32	2.08E+01	1.30E+02	6.79E-01	6.63E-01	3.25E+00	1.79E+03	1.79E+01	**7.27E+00**
Di-n-octyl phthalate	8.54	5.43	2.69E+05	1.68E+06	6.79E-01	6.63E-01	6.46E+00	2.90E+06	2.90E+04	**5.81E+01**
Hexachlorobutadiene	4.72	2.10	1.27E+02	7.94E+02	6.79E-01	6.63E-01	3.87E+00	7.34E+03	7.34E+01	**1.08E+01**
Hexachlorocyclopentadiene	4.63	2.02	1.06E+02	6.61E+02	6.79E-01	6.63E-01	3.80E+00	6.36E+03	6.36E+01	**1.04E+01**
Hexachloroethane	4.03	1.51	3.24E+01	2.02E+02	6.79E-01	6.63E-01	3.40E+00	2.53E+03	2.53E+01	**8.01E+00**
Methylcyclohexane	3.59	1.12	1.33E+01	8.30E+01	6.79E-01	6.63E-01	3.10E+00	1.26E+03	1.26E+01	**6.59E+00**

Notes:

a, log K_{ww} = 0.87*log K_{ow} - 2 (USEPA, 2007a; Jager, 1998)

b, Converted from wet weight to dry weight assuming 16% solids (USEPA, 2005; Jager, 1998)

c, K_{oc} values modeled based on regression equations from Gerstl (1990), for All Compounds: log K_{oc} = A*log K_{ow} + B, where A = slope and B = intercept.

d, K_d = f_{oc}*K_{oc}, where "foc" is the fraction of organic carbon in soil.

 f_{oc} is assumed to be: 0.01

e, BAF = K_{ww} (L/kg worm dw) / K_d (L/kg soil dw)

f, log K_{ow} values obtained from EPI SUITE program, KOWWIN module v 1.69.

BAF, bioaccumulation factor
dw, dry weight
ww, wet weight

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Table 5
Estimated Soil to Small Mammal Bioaccumulation Factors (BAF) for Non-Ionic Organic Compounds
Technical Memorandum: Proposed Wildlife Exposure Modeling Approach
Columbia Falls Aluminum Company
Columbia Falls, Montana

Analyte	log K_{ow}	Fat content of beef[c]	BAF$_{beef\ ww}$[b] d/kg beef$_{ww}$	BAF$_{plant\ ww}$[d] mg/kg plant$_{ww}$ per mg COPEC/kg soil$_{dw}$	BAF$_{invert\ ww}$[e] mg/kg inv$_{ww}$ per mg COPEC/kg soil$_{dw}$	BAF$_{MAX\ plant/invert\ ww}$[f] mg/kg tissue$_{ww}$ per mg COPEC/kg soil$_{dw}$	BAF$_{soil-mammal\ dw}$[a] mg/kg flesh$_{dw}$ per mg COPEC/kg soil$_{dw}$
Dibenzofuran	3.71	19%	2.12E-02	2.82E-01	2.71E+00	2.71E+00	5.60E-02
1,2,4,5-Tetrachlorobenzene	4.57	19%	3.48E-02	1.27E-01	3.95E+00	3.95E+00	1.33E-01
2-Chloronaphthalene	3.81	19%	2.29E-02	2.57E-01	2.83E+00	2.83E+00	6.32E-02
Hexachlorobutadiene	4.72	19%	3.66E-02	1.10E-01	4.22E+00	4.22E+00	1.49E-01
Hexachlorocyclopentadiene	4.63	19%	3.55E-02	1.20E-01	4.05E+00	4.05E+00	1.39E-01
Hexachloroethane	4.03	19%	2.66E-02	2.09E-01	3.12E+00	3.12E+00	8.07E-02
Methylcyclohexane	3.59	19%	1.92E-02	3.17E-01	2.57E+00	2.57E+00	4.82E-02

Notes:

a, BAF$_{soil-mammal}$ model based on LANL (2015) equation for Transfer Factor from soil to dry weight flesh (TF_flesh_dw):

$$BAF_{soil-mammal} = BAF_{beef} \times \left[\frac{(FIR_{MAX} \times BAF_{MAX\ plant/invert} + SIR_{MAX})}{(1-MC)} \right]$$

where:
BAF$_{soil-mammal\ dw}$ = Soil-to-small mammal BAF (kg soil, dw/kg flesh, dw)
BAF$_{beef\ ww}$ = Diet-to-beef transfer factor (d/kg beef$_{ww}$)
FIR$_{MAX\ ww}$ = Maximum food ingestion rate for LANL prey species (0.305 kg food$_{ww}$/d; LANL, 2015)
BAF$_{MAXPlant/Invert}$ = Maximum BAF for plant or invertebrate dietary items of the prey species (kg soil$_{dw}$/kg tissue$_{ww}$)
SIR$_{MAX}$ = Maximum incidental soil ingestion rate for LANL prey species (0.0193 kg soil$_{dw}$/d; LANL, 2015)
MC = Moisture content of flesh (assumed 68 percent per LANL, 2015)

b, Diet-to-beef transfer factor calculated based on RTI (2005), consistent with LANL (2017):

$$LogBAF_{beef\ ww} = Fat_{beef} \times (-0.099 \times \log K_{ow}^2 + 1.07 \times logKow - 3.56)$$

where:
BAF$_{beef\ ww}$ = Diet-to-beef transfer factor (d/kg beef$_{ww}$)
Fat$_{beef\ ww}$ = Fat content of beef; assumed to be 19 percent or 0.19 based on LANL (2017)
K$_{ow}$ = Octanol-water partitioning coefficient

c, Assumed fat content of beef of 19 percent consistent with LANL (2017)
d, BAF$_{plant\ ww}$, Soil-to-plant bioaccumulation factor calculated on wet weight basis by multiplying the plant BAF in Table 3 by 1-moisture content of plant leaves (1 - 0.85 = 0.15 per LANL, 2017).
e, BAF$_{invert\ ww}$, Soil-to-invertebrate bioaccumulation factor calculated on wet weight basis by multiplying the plant BAF in Table 3 by 1-moisture content in soil invertebrates (1 - 0.61 = 0.39; LANL, 2017).
f, Maximum soil-to-tissue BAF between higher of the BAF$_{plant\ ww}$ and BAF$_{invert\ ww}$

BAF, bioaccumulation factor
dw, dry weight
ww, wet weight

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Analyte	log K_{ow}	Maximum Surface Water Concentration (mg/L)	Maximum Sediment Concentration (mg/kg, dry weight)	Normalized BSAF (kg OC/kg lipid)[a]	Estimated Concentrations in Dietary Items of Aquatic Receptors (mg/kg, dry weight)							
					Aquatic Life Stage Benthic Invertebrates				Fish			
					BSAF[b]	BCF	Estimated Concentration	BSAF/BCF Reference	BSAF	BCF	Estimated Concentration	BSAF/BCF Reference
Metals												
Aluminum	NA	0.01	10.0	NA	7.40E-02	---	7.40E-01	Stanley et al. (2010)	---	9.24E+02	9.24E+00	Sample et al. (1996b)
Antimony	NA	0.01	10.0	NA	5.75E-01	---	5.75E+00	Dovick et al. (2015)	---	4.00E+00	4.00E-02	Sample et al. (1996b)
Arsenic	NA	0.01	10.0	NA	3.73E-01	---	3.73E+00	Bechtel-Jacobs (1998b)[c]	---	6.80E+01	6.80E-01	Sample et al. (1996b)
Barium	NA	0.01	10.0	NA	2.82E+00	---	2.82E+01	Hamilton et al. (2002)	---	2.98E+02	2.98E+00	Nakamoto and Hassler (1992)
Beryllium	NA	0.01	10.0	NA	1.67E-01	---	1.67E+00	Hamilton et al. (2002)	---	7.60E+01	7.60E-01	Sample et al. (1996)
Cadmium	NA	0.01	10.0	NA	4.59E-01	---	4.59E+00	Bechtel-Jacobs (1998b)[c]	---	4.96E+04	4.96E+02	Sample et al. (1996b)
Chromium	NA	0.01	10.0	NA	8.30E-02	---	8.30E-01	Bechtel-Jacobs (1998b)[c]	---	1.20E+01	1.20E-01	Sample et al. (1996b)
Copper	NA	0.01	10.0	NA	6.61E-01	---	6.61E+00	Bechtel-Jacobs (1998b)[c]	---	1.16E+03	1.16E+01	Sample et al. (1996b)
Lead	NA	0.01	10.0	NA	8.00E-02	---	8.00E-01	Bechtel-Jacobs (1998b)[c]	---	1.80E+02	1.80E+00	Sample et al. (1996b)
Nickel	NA	0.01	10.0	NA	1.34E-01	---	1.34E+00	Bechtel-Jacobs (1998b)[c]	---	4.2E+02	4.2E+00	Sample et al. (1996b)
Selenium	NA	0.01	10.0	NA	3.75E+00	---	3.75E+01	Hamilton et al. (2002)	---	1.0E+04	1.0E+02	Sample et al. (1996b)
Silver	NA	0.01	10.0	NA	1.80E-01	---	1.80E+00	Hirsch (1998)	---	4.2E+02	4.2E+00	Garnier-Laplace et al. (1992)
Thallium	NA	0.01	10.0	NA	2.00E-02	---	2.00E-01	Turner et al. (2013)	---	1.36E+02	1.36E+00	Sample et al. (1996b)
Vanadium	NA	0.01	10.0	NA	2.50E-01	---	2.50E+00	Hamilton et al. (2002)	---	2.52E+03	2.52E+01	CECBP (2008)
Zinc	NA	0.01	10.0	NA	8.40E-01	---	8.40E+00	Bechtel-Jacobs (1998b)[c]	---	3.9E+03	3.86E+01	Sample et al. (1996b)
Inorganics - Other Inorganics												
Cyanide	NA	0.01	10.0	NA	0.0E+00	0.0E+00	0.0E+00	Lanno and Menzie (2005)	0.0E+00	0.0E+00	0.0E+00	Lanno and Menzie (2005)
Fluoride	NA	0.01	10.0	NA	---	Regression	2.43E+01	Derived based on Aguirre-Sierra et al. (2013)	---	Regression	1.92E+01	Derived based on Shi et al. (2009)
Semi-volatile Organic Compounds (SVOCs) - Polycyclic Aromatic Hydrocarbons (PAHs)												
Low Molecular Weight (LMW) PAHs:												
Acenaphthene	4.01	0.001	0.1	0.704	4.58E+00	---	4.58E-01	DiToro and McGrath (2000)	5.63E+00	---	5.63E-01	DiToro and McGrath (2000)
Acenaphthylene	3.22	0.001	0.1	0.754	4.90E+00	---	4.90E-01	DiToro and McGrath (2000)	6.04E+00	---	6.04E-01	DiToro and McGrath (2000)
Anthracene	4.53	0.001	0.1	0.673	4.37E+00	---	4.37E-01	DiToro and McGrath (2000)	5.38E+00	---	5.38E-01	DiToro and McGrath (2000)
Fluorene	4.21	0.001	0.1	0.692	4.50E+00	---	4.50E-01	DiToro and McGrath (2000)	5.53E+00	---	5.53E-01	DiToro and McGrath (2000)
Naphthalene	3.36	0.001	0.1	0.745	4.84E+00	---	4.84E-01	DiToro and McGrath (2000)	5.96E+00	---	5.96E-01	DiToro and McGrath (2000)
Phenanthrene	4.57	0.001	0.1	0.670	4.36E+00	---	4.36E-01	DiToro and McGrath (2000)	5.36E+00	---	5.36E-01	DiToro and McGrath (2000)
Total LMW PAHs							2.76E+00				3.39E+00	

EHS Support

Analyte	log K_{ow}	Maximum Surface Water Concentration (mg/L)	Maximum Sediment Concentration (mg/kg, dry weight)	Normalized BSAF (kg OC/kg lipid)[a]	Estimated Concentrations in Dietary Items of Aquatic Receptors (mg/kg, dry weight)							
					Aquatic Life Stage Benthic Invertebrates				Fish			
					BSAF[b]	BCF	Estimated Concentration	BSAF/BCF Reference	BSAF	BCF	Estimated Concentration	BSAF/BCF Reference
High Molecular Weight (HMW) PAHs:												
Benzo(a)anthracene	6.71	0.001	0.1	0.556	3.61E+00	---	3.61E-01	DiToro and McGrath (2000)	4.45E+00	---	4.45E-01	DiToro and McGrath (2000)
Benzo[A]Pyrene	6.11	0.001	0.1	0.586	3.81E+00	---	3.81E-01	DiToro and McGrath (2000)	4.69E+00	---	4.69E-01	DiToro and McGrath (2000)
Benzo(b)fluoranthene	6.27	0.001	0.1	0.578	3.76E+00	---	3.76E-01	DiToro and McGrath (2000)	4.62E+00	---	4.62E-01	DiToro and McGrath (2000)
Benzo(g,h,i)perylene	6.51	0.001	0.1	0.566	3.68E+00	---	3.68E-01	DiToro and McGrath (2000)	4.53E+00	---	4.53E-01	DiToro and McGrath (2000)
Benzo(k)fluoranthene	6.29	0.001	0.1	0.577	3.75E+00	---	3.75E-01	DiToro and McGrath (2000)	4.61E+00	---	4.61E-01	DiToro and McGrath (2000)
Chrysene	5.71	0.001	0.1	0.607	3.94E+00	---	3.94E-01	DiToro and McGrath (2000)	4.85E+00	---	4.85E-01	DiToro and McGrath (2000)
Dibenz(A,H)Anthracene	6.71	0.001	0.1	0.556	3.61E+00	---	3.61E-01	DiToro and McGrath (2000)	4.45E+00	---	4.45E-01	DiToro and McGrath (2000)
Fluoranthene	5.08	0.001	0.1	0.641	4.17E+00	---	4.17E-01	DiToro and McGrath (2000)	5.13E+00	---	5.13E-01	DiToro and McGrath (2000)
Indeno (1,2,3-CD) Pyrene	6.72	0.001	0.1	0.555	3.61E+00	---	3.61E-01	DiToro and McGrath (2000)	4.44E+00	---	4.44E-01	DiToro and McGrath (2000)
Pyrene	4.92	0.001	0.1	0.650	4.23E+00	---	4.23E-01	DiToro and McGrath (2000)	5.20E+00	---	5.20E-01	DiToro and McGrath (2000)
Total HMW PAHs					3.82E+00						4.70E+00	
Semi-volatile Organic Compounds (SVOCs) - Non-PAH SVOCs												
2,3,4,6-Tetrachlorophenol	4.09	0.001	0.1	0.699	4.54E+00	---	4.54E-01	DiToro and McGrath (2000)	5.59E+00	---	5.59E-01	DiToro and McGrath (2000)
2-Chloronaphthalene	3.81	0.001	0.1	0.716	4.66E+00	---	4.66E-01	DiToro and McGrath (2000)	5.73E+00	---	5.73E-01	DiToro and McGrath (2000)
Bis(2-ethylhexyl)phthalate	8.39	0.001	0.1	0.480	3.12E+00	---	3.12E-01	DiToro and McGrath (2000)	3.84E+00	---	3.84E-01	DiToro and McGrath (2000)
Dibenzofuran	3.71	0.001	0.1	0.723	4.70E+00	---	4.70E-01	DiToro and McGrath (2000)	5.78E+00	---	5.78E-01	DiToro and McGrath (2000)
Di-n-octyl phthalate	4.61	0.001	0.1	0.668	4.34E+00	---	4.34E-01	DiToro and McGrath (2000)	5.34E+00	---	5.34E-01	DiToro and McGrath (2000)
Hexachlorobenzene	5.86	0.001	0.1	0.599	3.89E+00	---	3.89E-01	DiToro and McGrath (2000)	4.79E+00	---	4.79E-01	DiToro and McGrath (2000)
Hexachlorobutadiene	4.72	0.001	0.1	0.662	4.30E+00	---	4.30E-01	DiToro and McGrath (2000)	5.29E+00	---	5.29E-01	DiToro and McGrath (2000)
Pentachlorophenol	4.74	0.001	0.1	0.661	4.30E+00	---	4.30E-01	DiToro and McGrath (2000)	5.29E+00	---	5.29E-01	DiToro and McGrath (2000)

Notes:

Maximum exposure point concentrations are example values to illustrate the calculation of COPEC concentrations in tissue; these values are not representative of exposure concentrations at the Site.

NA, Normalized BSAF was not applicable for metals

a, Normalized BSAF (kg OC / kg lipid) calculated based on K_{ow}, where BSAF $= K_{ow}^{-0.038}$ (DiToro and McGrath 2000)

b, For non-ionic organic constituents, dry weight BSAF calculated from sediment organic carbon and lipid normalized BSAF as follows:

$$BSAF_{dry\ weight} = BSAF_{norm} \times f_{lip;id} \times \frac{1}{f_{oc}}$$

where: $BSAF_{norm}$ = Normalized BSAF (kg OC/kg lipid)

f_{lipid} = Fraction of lipids in prey item expressed on a dry weight basis (0.065, invertebrates; 0.08, fish)

f_{oc} = Fraction of sediment organic carbon expressed on a dry weight basis (0.01 or 1.0%)

c, Median BSAF for non-depurated invertebrates determined by Bechtel-Jacobs (1998b)

BCF, bioconcentration factor

BSAF, biota-sediment accumulation factor

kg OC/kg lipid, kilogram organic carbon per kilogram lipid

EHS Support

Analytes	Avian Receptors				Mammalian Receptors			
	Chronic TRV_Low [a]	Chronic TRV_High [b]	Test Animal	Source	Chronic TRV_Low [a]	Chronic TRV_High [b]	Test Animal	Source
	(mg/kg-bw/d)				(mg/kg-bw/d)			
Metals								
Aluminum	110	1100	Ringed dove	Carriere et al. (1986); as cited in LANL EcoRisk	Narrative	Narrative	---	USEPA (2003b)
Antimony	NA	NA	--	--	0.059	2.76	geometric mean	USEPA (2005b); TechLaw (2008)
Arsenic	2.24	4.51	geometric mean	USEPA (2005c); TechLaw (2008)	1.04	4.55	geometric mean	USEPA (2005c); TechLaw (2008)
Barium	73.5	131	geometric mean	LANL (2003)	51.8	82.7	geometric mean	USEPA (2005d); TechLaw (2008)
Beryllium	NA	NA	--	--	0.532	0.67	geometric mean	USEPA (2005e); TechLaw (2008)
Cadmium	1.47	6.35	geometric Mean	USEPA (2005f); TechLaw (2008)	0.77	6.87	geometric mean	USEPA (2005f); TechLaw (2008)
Chromium	2.66	15.6	geometric mean	USEPA (2008b); TechLaw (2008)	2.4	58.2	geometric mean	USEPA (2008b); TechLaw (2008)
Cobalt	7.61	20.16	geometric mean	USEPA (2005g); TechLaw (2008)	7.33	18.9	geometric mean	USEPA (2005g); TechLaw (2008)
Copper	4.05	34.8	geometric mean	USEPA (2007b); TechLaw (2008)	5.6	82.7	geometric mean	USEPA (2007b); TechLaw (2008)
Lead	1.63	44.6	geometric mean	USEPA (2005h); TechLaw (2008)	4.7	186.4	geometric mean	USEPA (2005h); TechLaw (2008)
Manganese	179	377	geometric mean	USEPA (2007c); TechLaw (2008)	51.5	146	geometric mean	USEPA (2007c); TechLaw (2008)
Mercury	0.45	0.91	Japanese quail	Hill and Schaffer (1976), as cited in Sample et al. (1996b)	1	NA	mink	Aulerich et al. (1974), as cited in Sample et al. (1996b)
Nickel	6.71	18.6	geometric mean	USEPA (2007d); TechLaw (2008)	1.7	14.8	geometric mean	USEPA (2007d); TechLaw (2008)
Selenium	0.3	0.82	geometric mean	USEPA (2007e); TechLaw (2008)	0.143	0.66	geometric mean	USEPA (2007e); TechLaw (2008)
Silver	2.02	60.5	geometric mean	USEPA (2006); TechLaw (2008)	6.02	119	geometric mean	USEPA (2006); TechLaw (2008)
Thallium	0.35	3.5	starling	Schafer (1972), as cited in LANL EcoRisk	0.0071	0.071	rat	Formigli et al. (1986), as cited in LANL EcoRisk
Vanadium	0.344	1.7	geometric mean	USEPA (2005i) TechLaw (2008)	4.16	9.44	geometric mean	USEPA (2005i) TechLaw (2008)
Zinc	66.1	171	geometric mean	USEPA (2007e); TechLaw (2008)	75.4	298	geometric mean	USEPA (2007e); TechLaw (2008)
Inorganics - Other Inorganics								
Cyanide	0.04	0.4	American kestrel	Wiemeyer et al. (1986), as cited in LANL EcoRisk	68.7	687	rat	Tewe and Manner (1981), as cited in LANL EcoRisk
Fluoride	12.2	122	Eastern screech owl	Pattee et al. (1988), as cited in LANL EcoRisk	26.6	49	mink	Aulerich et al. (1987), as cited in LANL EcoRisk
Semi-volatile Organic Compounds (SVOCs) - Polycyclic Aromatic Hydrocarbons (PAHs)								
Total LMW PAHs	16.1	161	mallard	Patton and Dieter 1980	65.6	356	geometric mean	USEPA (2007g); TechLaw (2008)
Total HMW PAHs	2	20	European starling	Trust et al. (1994), as cited in USEPA (2007g)	0.615	38.4	geometric mean	USEPA (2007g); TechLaw (2008)
Semi-volatile Organic Compounds (SVOCs) - Non-PAH SVOCs								
1,2,4,5-Tetrachlorobenzene	No TRV	No TRV	---	---	No TRV	No TRV	---	---
2,3,4,6-Tetrachlorophenol	No TRV	No TRV	---	---	No TRV	No TRV	---	---
2-Chloronaphthalene	No TRV	No TRV	---	---	No TRV	No TRV	---	---
Bis(2-ethylhexyl)phthalate	1.1	11	Ringed dove	Sample et al. (1996b), as cited in LANL EcoRisk	18.3	183	mouse	Sample et al. (1996b), as cited in LANL EcoRisk
Butylbenzylphthalate	0.11[c]	1.1[c]	Ringed dove	Sample et al. (1996b)	159	1590	rat	NTP (1985), as cited in LANL EcoRisk
Dibenzofuran	No TRV	No TRV	---	---	No TRV	No TRV	---	---
Di-n-butyl phthalate	0.11	1.1	Ringed dove	Sample et al. (1996b)	550	1833	mouse	Sample et al. (1996b)
Di-n-octyl phthalate	0.11[c]	1.1[c]	Ringed dove	Sample et al. (1996b)	65.1	651	mouse	IT Corporation (1997), as cited in LANL (2017)
Hexachlorobenzene	5	50	Japanese quail	Carpenter et al. (1985), as cited in LANL EcoRisk	7.1	71	Deer mouse	Schafer et al. (1985), as cited in LANL EcoRisk
Hexachlorobutadiene	No TRV	No TRV	---	---	200	2000	Rat	Kociba et al. (1977), as cited in USEPA (1999)

EHS Support

ED_002345C_00006500-00049

Analytes	Avian Receptors				Mammalian Receptors			
	Chronic TRV$_{Low}$ [a] (mg/kg-bw/d)	Chronic TRV$_{High}$ [b] (mg/kg-bw/d)	Test Animal	Source	Chronic TRV$_{Low}$ [a] (mg/kg-bw/d)	Chronic TRV$_{High}$ [b] (mg/kg-bw/d)	Test Animal	Source
Hexachlorocyclopentadiene	No TRV	No TRV	---	---	No TRV	No TRV	---	---
Hexachloroethane	No TRV	No TRV	---	---	No TRV	No TRV	---	---
Pentachlorophenol	6.73	52	geometric mean	USEPA (2007h); TechLaw (2008)	8.42	22.7	geometric mean	USEPA (2007h); TechLaw (2008)
Volatile Organic Compounds (VOCs)								
Methylcyclohexane	No TRV	No TRV	---	---	No TRV	No TRV	---	---
Dioxin/Furans								
2,3,7,8-TCDD	0.000014	0.00014	Ring-neck pheasant	Sample et al (1996)	0.000000562	0.00000376	geometric mean	Murray et al. (1979), as cited in LANL EcoRisk

Notes:
a, NOAEL is no observable adverse effects level.
b, LOAEL is low observable adverse effects level.
c, Di-n-butyl pthalate used as a surrogate for avian exposure to phthalates.
---, Appropriate data are not available from published literature to derive NOAEL and LOAEL values.
NA, Toxicity Reference Value not available.
bw/d, body weight per day.
TRV, toxicity reference value.

EHS Support

ED_002345C_00006500-00050

a) Fluoride bioaccumulation into white-clawed crayfish (*Austropotamobius pallipes*) as a function of water concentration (Aguirre-Sierra et al., 2013).
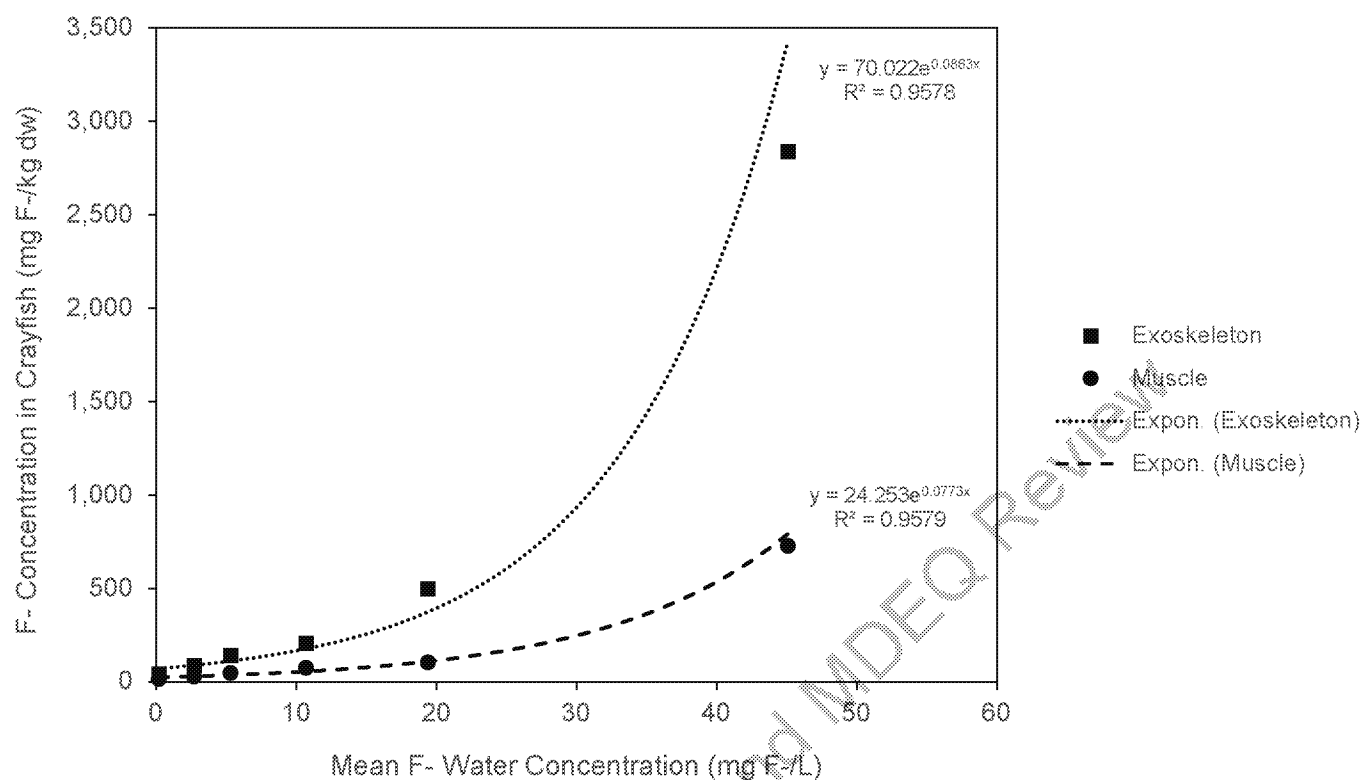
b) Fluoride bioaccumulation into Siberian sturgeon (*Acipenser baerii*) as a function of water concentration (Shi et al., 2009).

EHS Support	COLUMBIA FALLS ALUMINUM CO. COLUMBIA FALLS, MONTANA	Fluoride Water-to-Biota Bioaccumulation Relationships for Benthic Invertebrates and Fish	Figure 1